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Impact of Climate Change and Variability on Pastand Future Rice (Oryza Satival) Productivity in Fogera Plain, Lake Tana Sub Basin Ethiopia

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COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

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IMPACT OF CLIMATE CHANGE AND VARIABILITY ON PAST AND FUTURE RICE (*Oryza sativaL)* PRODUCTIVITY IN FOGERA PLAIN, LAKE TANA SUB BASIN ETHIOPIA

M.Sc. Thesis

BY

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Impact of Climate Change and Variability on Past and Future Rice *(Oryza sativaL)* Productivity in Fogera plain, Lake Tana Sub Basin Ethiopia

By

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Advisor: Solomon Addisu (Associate Professor)

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THESIS APPROVAL SHEET

As a member of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defence examination, we have read and evaluated this thesis prepared by **Mr Wubet Ashagrie Alemu** entitled " **Impact of climate change and variability on past and future rice productivity in Fogera plain, Lake Tana sub basin Ethiopia**". We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in **"Environment and Climate Change"**

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This is to certify that this thesis entitled **"Impact of climate change and variability on past and future rice productivity in Fogera plain, Lake Tana Sub basin Ethiopia"** which is submitted to the graduate program of the College of Agriculture and Environmental Sciences, Bahir Dar University, for partial fulfillment of the requirements for the award of the degree of master science (M.Sc.) in **"Environment and Climate Change "** by **Wubet Ashagrie Alemu** (ID.No.BDU1401324) is entirely my own work under the supervision of Solomon Addisu (Associate Professor) from Bahir Dar University. All additional sources of materials are accordingly acknowledged and this work has not been previously submitted to any academic institution for an award of any academic degree by authors.

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DEDICATION

This thesis is dedicated to my beloved mother Metn Awoke who always supports me and is eager to see my achievement.

STATEMENT OF THE AUTHOR

I verify and affirm that the work in this thesis is completely my own original work. I adhered to the ethical and technical norms of study while I planned, gathered, evaluated and put together my thesis. Each scholarly work cited in the thesis has been properly cited. This thesis is submitted in partial fulfillment of the requirements for the award of a degree of Master of Science (M.Sc.) in environment and climate change at Bahir Dar University. The thesis is made available to borrowers in accordance with library policies after being deposited at the Bahir Dar University library. I can declare with confidence that no other school, anywhere, has accepted this thesis to grant any type of academic credential, certificate or degree. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of the source is made. Requests for permission for an extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the dean of the school of graduate studies when, in his or her judgment, the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author and advisors of this thesis.

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LIST OF ABBREVIATIONS AND ACRONYMS

CV	Coefficient of Variation
CSA	Central Static Agency
CMhyd	Climate Model data for hydrologic modeling
CMIP5	Model Inter comparison Project Phase 5
CMIP6	Coupled Model Inter comparison Project Phase 6
EIAR	Ethiopian institute of agriculture research
EOS	End date of growing season
Esgf	Earth system grid federation
IPCC	Intergovernmental Panel on Climate Change
Max	Maximum
Min	Minimum
MMK	Modified Mann-Kendall
Netcdf	Network Common Data Form
EMI	Ethiopia Metrological institute
PCI	Precipitation Concentration Index
SAI	Standard Anomaly Index
SSP	Shared socioeconomic pathway
SOS	Start date of growing season
SDV	Standard deviation

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Abstract

Future climate change is expected to impact on rice (Oryza sativa L.) productivity. The study tried to investigate the impact of climate change and variability on past and future rice (Oryza sativa L.) productivity in Fogera plain. In this study, long-term observed climate data (1993–2022) and projected (2025–2086) rainfall and temperature used to analyze change and variability, projected change and impact on rice yield. Variability was analyzed through coefficient of variation, precipitation concentration index and Standard anomaly index. Whereas trend was analyzed through Sen's slop, percent change and Modified Mann kandel test. CMhyd software were used for both extracted Netcdf file and bias correction the future precipitation and temperature for three shared socioeconomic pathways SSP1-2.6 (sustainable / with climate policies), SSP2-4.5 (medium) and SSP5-8.5(worst / in the absence of climate policies) of future socioeconomic conditions. The start, length of kiremt season and maximum temperature coefficient of variation was less than 10% in the plain. In Fogera plain over all mean precipitation concentration index were 23.1 which show very high concentrations of annual rainfall distribution. The annual and kiremt season rainfall insignificantly increase in Wereta and Addis Zemen but significant decreasing in Wanzaye. Late start of season (SOS) and decreasing in length of growing season was observed in the plain. Annual rainfall totals decreasing in Addis Zemen station in all scenarios except SSP5-8.5(2056-2086) but annual rainfall at Wereta station and Wanzaye stations is expected to increase by SSP1-2.6 and SSP5-8.5 both in 2025-2055 and 2056-2086. Projected change of annual and seasonal minimum and maximum temperature showed rise in under SSP1-2.6, SSP2-4.5 and SSP5-8.5 by 2025-2055 and 2056-2086 in the plain. Rice yields showed positive correlation with length and end of growing season. Rice yields showed negative correlation with onset of season, maximum and minimum temperature in all stations. The rice yield variation in Wanzaye, Wereta and Addis Zemen station were explained jointly by 77%, 62% and 64% of the rainfall and temperature variables while the remaining 23%, 38 % and 36% of the variations could be by other factors. The simulated yield of rice is varied with location and type of scenarios used in the future. Yield of rice would be expected to increase under the SSP1-2.6 scenario in all growing locations but decrease under the SSP5-8.5 scenario in all growing locations of Fogera plain.

Keywords: Trend, Future climate, CMhyd, CMIP6, Correlation

CHAPTER 1 INTRODUCTION

1.1 Background of the study

Climate change is the current issue which attracting the attention of experts, organizations and government policy makers (Toride *et al*., 2018; Sayadi *et al.*, 2019; Getachew & Manjunatha, 2021; Belay *et al.*, 2021). Climate change has been observed since 1950 as the atmosphere has warmed, the sea level has risen, and the amount of snow and ice have diminished (Arora, 2019; Pörtner *et al.,* 2022). The sixth assessment report (AR6) of the United Nations intergovernmental panel on climate change (IPCC) reported that the global surface temperature (GST) for 2001–2020 is 0.99 °C higher than that for 1850–1900 and that global surface temperature increases in the 21st century will exceed 1.5 °C and 2 °C unless significant global reductions in CO2 and other greenhouse gas emissions are implemented in the upcoming decades (IPCC, 2022). Average temperature increased (Polya, 2023). Annual amount, intensity and distribution of rainfall Change (Calvin *et al.*, 2023). Rapid industrialization over the last century has contributed to a major improvement in the living standards of millions of people, it has also brought with it serious problems. Industrial and agricultural emissions of carbon dioxide (CO2), methane (CH4), chlorofluorocarbons, nitrous oxide, and other gases, mainly from the burning of fossil fuels, are resulting in an increase of these gases in the earth's atmosphere. This the increase in greenhouse gas emissions has resulted in a climatic imbalance in the Earth's atmosphere (Althor *et al*., 2016; Toride *et al.,* 2018). Emissions from agriculture and energy sectors double since 1994. These two sectors are the major emitters in Ethiopia accounting for 85% and 15% of the total gas emission respectively (Belay *et al*., 2021). In the coming decades until the end of the century, the average temperature is projected to continue to increase (Sharma & Ravindranath, 2019; Abate & Schaap, 2022; Pörtner *et al.,* 2022)**.**

Africa produces around 60% of rice the rest comes from imports to fulfill domestic demand. Over the past 10 years, the rice-agricultural area increased nearly 40%, while average yield remained stagnant (Mukhopadhyay & Das, 2023). Agricultural productivity is very sensitive to climate and weather conditions influenced by different variables like soil moisture, temperature, pest, precipitation, growing season length and timing of frost (Dhurandher *et al*., 2024). Climate change is projected to overall decrease in the yields of cereal crop in Africa through shortening growing season length, increasing water stress and increasing incidence of diseases, pests and weeds outbreaks (Niang *et al.*, 2017). The rise temperature negatively affect rice production in African countries (Mukhopadhyay & Das, 2023). Rice crop are temperature sensitive; where an increase in temperature affects the reproductive and developmental stages of rice (Khanal *et al.*, 2024). Both low and excessive rainfalls can have a negative impact on rice yield.

In Ethiopia, rain-fed agriculture is a major source of income and subsistence for the nation and it plays a great role in economic growth and development. Under Ethiopia growth and transformation plan (GTP) and agricultural development-led industrialization (ADLI) policies the agricultural sector is the country's main source of economic growth with a focus on increasing production and productivity. It accounting for 44% of GDP, 85% of exports, and 85% of total employment out of this crop production accounts for more than 65% of the agricultural GDP and employs 67% of the population in Ethiopia (Abeje & Alemayehu, 2019). But agriculture is the most susceptible sector to climate change related hazards. This is due to the fact that climate change affects the two most important direct agricultural production inputs and these are precipitation and temperature (Alemayehu & Bewket, 2016; Getachew, 2018). The productivity has direct dependency on rainfall received during the crop season. In the early 1970s Ethiopia was hit by a severe famine which took the lives of hundreds of thousands of human beings. As a response to this dramatic event and aiming at the long-term enhancement of food security, the North Korean development cooperation introduced rice cultivation in Ethiopia, first in the Fogera and Gambella Plains (Tadesse., 2018). The Ethiopian government recognized that rice can significantly contribute to improving food security and poverty reduction. In recent years the demand for rice is rising fast in both national and regional markets because it is used for different purposes and food types (Astewel, 2017). According to Ethiopian institute of agriculture research (EIAR), (2020),75% of rice producers were found in South and North Gondar of Amhara region; while 18.8 % and 3.6% were found in Ilu Ababora zone of Oromia and Bench-Maji zone of SNNPR, respectively. South Gondar is a major rice growing area in Ethiopia accounts nearly 78.19% of rice area coverage and 83.53% of volume of production of rice in the Amhara region (CSA, 2021). Fogera plain is a major rice growing area in Ethiopia accounts nearly 68% of rice area coverage and 71% of volume of production of rice (CSA, 2020). The average rice productivity in Ethiopia was estimated at 2.81 t/ ha, which is much lower than the World's average of 4.7 tons per hectare (FAOSTAT, 2019). The average rice productivity in Fogera plain is at farmers level (4- 9 t/ha) but as compared with other countries (12-14 t/ha in Egypt, Australia and China) it is very low (Fahad *et al*., 2019). Because of these according to the data from Ethiopian Revenue and Customs Authority (ERCA), rice imports grew from 22,500 tons in 2008 to 533,620 tons in 2019. Rice Production and area harvested in Ethiopia rises to 189649 tons and 62,551 hectare in 2020 (FAO, 2022). The major rice production, which is found in the North-western part of Ethiopia (Amhara Region) accounts for about 75% of the area coverage of about 39,830 hectare and 80% of the production 119, 384.56 tons, other regions contributed 25% of the area coverage 13,276.75 hectare and 20% of the rice production 29, 846.14 tons (CSA, 2018).

1.2 Statement of Problem

The population of Ethiopia is expected to grow to 133.5 million people by 2030 and it exceeds 172 million by 2050 (Bekele & Lakew, 2014) which require extra food production. But in Amhara National Regional State in general and in South Gondar Zone in particular, where available agricultural land will continue to decrease because land holdings have been under continuous sharing, fragmentation and agricultural lands converted to urban areas in the continuing urbanization (kelemu, 2021). So Many farmers have very small farm land size, and are unable to compensate for unit area yield loss by increasing area of production.

Fogera plain is a major rice growing area in Ethiopia accounts nearly 68% of rice area coverage and 71% of volume of production of rice (CSA, 2020).Farmers who live in this area uses rice as food security, source of income and employment .They prefer rice due to its relative high productivity as compared to other cereals (Ethiopian institute of agriculture research, 2020). But productivity and production of rice is affected by climate change and variability. Climate change altered the annual amount, intensity and distribution of rainfall (Musau *et al.*, 2016). Poor rainfall distribution, particularly in the early(hinders agricultural operations) and late growth stages of the crop (after the mid of September) with the unsatisfactory amount of rainfall during flowering and milking stages to affects fertilization, grain filling and reduce final yield .High amount of rainfall during ripening period causes fall of rice seed. Therefore rice were harvested before reaching maturity period because farmers preferred harvesting rice than 100% production loss

(Molla, 2021). The increase of the mean seasonal temperature and reduction of rainfall could lead to the reduction of rice production (Zhao *et al*., 2022).

The Ethiopian government has medium development plan which is substituting import rice with domestic rice production and has a long term plan to export rice. There is agape, many researchers have investigated the potential effects of the changing climate on rice production and productivity on world, national ,regional and Zonal scales (Adhikari *et al.,* 2017; Getachew, 2017; Molla *et al.,* 2020; Zhao *et al.*, 2022; Vyas Pandey, 2023) but these studies were inconsistent. These studies (Getachew, 2017; Molla *et al.,* 2020) try to investigate climate variability impact on rice production but not cover productivity in south Gondar and Fogera plain. No studies conducted about predicting potential effects of the changing climate on future rice production and productivity in the context of Fogera plain. Predicting rice productivity used to alleviate poverty and contribute towards food security. Therefore this study was addressing the impacts of climate change and variability on past and future rice crop productivity Fogera plain, south Gondar zone.

1.3. Research Questions

The study would be tried to answer following questions:

1) What Wes the trend and variability of rainfall and temperature?

2) What would be future local climate (temperature and rainfall)?

3) What would be rice productivity in the future?

1.4. Objectives

1.4.1. General objective

The general objective of this study was to analyses climate change and variability impacts on rice (*Oryza sativa L.)* past and future productivity in Fogera plain.

1.4.2. Specific objectives

1) To analyze the trend and variability of rainfall and temperature.
2) Predict future local temperature and rainfall change.
3) To estimate future rice productivity change.

1.5. Significance of the Study

The findings of this study could be used as inputs for researchers, experts and decision makers. Therefore, predicting rice crop yields helps policymakers to make timely import and export decisions. Used as reference/baseline for further studies. Hence, this study was expected to fill the knowledge gap on the understanding of impact of past and future climate in Fogera plain, on rice productivity and enhancing the case of climate information to increase productivities under changing and variable climate. It would be helpful for farmers; to match the cropping season with the time sowing date.

1.6. Scope of the study

Scope of the study focused impact of climate change and variability on rice production in Fogera plain. The study would be limited only Fogera plain with in a period from1993-2086 year.

CHAPTER 2 LITERATURE REVIEW

2.1 Historical Rainfall Trend and Variability

Rainfall trends examine by Mann Kendall test and the Sen's slope estimates over the Lake Tana basin, the results showed that the annual rainfall is increasing but at a statistically insignificant rate (Weldegerima *et al.*, 2018). The rainy rainfall season accounts for 78% of total annual rainfall in the basin, while *bega* and *belg* provide 9.4% and 12.5%, respectively. Annual and seasonal rainfall at five stations, by using the innovative trend analysis method (ITAM), Mann-Kendall (MK) and Sen's slope estimator test. The result showed that the trend of annual rainfall was increasing in Gondar, Motta and Bahir Dar stations. However, the trends in Dangla and Adet stations showed a decreasing trend and The trend of rainfall in May, June, July, August, and September was increasing(Tariku *et al.,* 2021). The trend of precipitation prediction did not show a consistent over the Lake Tana basin (Gedefaw *et al.*, 2018; Getachew & Manjunatha, 2021). Based on precipitation data from two global climate models (GCMs) output of HadCM3 and CGCM3,the findings indicated that precipitation extremes over the Blue Nile basin are likely to increase (Yohannes, 2015).

Trends which show significant decreasing were shown in annual average rainfall for Wanzaye but increasing at Amedber, Wereta and Addis Zemen. The trends of Kiremt rainfall show decreasing in Wanzaye and Amedber but increasing in Wereta and Addis Zemen. *Bega* rainfall show increasing trend at Addis Zemen, Wereta. *Belg* rainfall show decreasing trend in Wereta and increasing trends at Amedber and Addis Zemen (Dawit *et al*., 2019). Annual and *kirem*t rainfall shows increasing at Addis Zemen and Wereta. *Bega* rainfall shows increasing at Addis Zemen and Wereta. *Belg* rainfall decreasing in Addis Zemen and Wereta (Birara *et al*., 2018). Annual average rainfall shows decreasing trend in Yifag and Hamusit station (Addisu *et al*., 2015). Seasonal and annual rainfall show decreasing trend at Wereta stations (Molla *et al.,* 2020). Seasonal and annual rainfall show increasing trend in Addis Zemen (Meseret & Bhat, 2020). There was no rainfall trend in Addis Zemen (Enyew. *et al.*, 2014).

Rainfall anomaly at Wereta years 1985, 1986, 1990, 1993, 1997, 2001, 2002, 2003, 2004,2007,2009, 2011, 2012, 2013 and 20014 were dry years with rainfall less than the mean of the study period while the year 1992 was the wettest and conversely the year

1993 was the driest year (kelemu, 2021). The precipitation concentration index (PCI) of annual rainfall is 25, 24.4 and 22.8 for Addis Zemen, Wereta and Wanzaye stations respectively this shows strongly irregular distribution but kiremt rainfall moderately distributed in Addis Zemen and uniformly distributed in Wereta and Wanzaye station and b*elg* rainfall is irregular distribution in all Addis Zemen ,Wereta and Wanzaye station (Dawit et al., 2019). Coefficients of variation (CV) of kiremt rainfall are (19%) uniform for Wereta stations (kelemu, 2021). Mean annual rainfall of CV of Hamusit (22%) were moderate and Yifag stations (17%) were uniform (Addisu et al., 2015). The coefficients of variation of annual rainfall are 27.99% for Addis Zemen stations, is moderately variable (Getachew, 2018).The coefficients of variation of annual rainfall are 38% high variation, 15% uniform and 16% uniform for Addis Zemen, Wereta and Wanzaye stations respectively (Dawit et al., 2019). The coefficients of variation of annual rainfall are 28% moderately variable and 17% for Addis Zemen and Wereta stations respectively, CV of kiremt rainfall are 22 % moderately variable and 17% uniform for Addis Zemen and Wereta stations respectively and CV in Addis Zemen 50% and 47% for *bega* and *belg* season, Wereta 52% and 33% for *bega* and *belg* season. Therefore, annual rainfall moderate and uniform in Addis Zemen and Wereta and *bega* rainfall in Addis Zemen and Wereta station is irregular distribution but kiremt rainfall uniformly distributed in Wereta and moderately distributed in Addis Zemen station and *belg* rainfall is irregular distributed in Addis Zemen and Wereta station (Birara *et al.*, 2018).

2.1.1 Rainfall and Crop growing season

Ethiopia has three rainfall seasons: *bega, belg,* and *kiremt*. The primary rainy season, *kiremt* occurs from June to September and accounts for 50–80% of annual rainfall .*Belg* which often has considerably less rainfall and occurs from March to May and *bega* occurring from October to February. Start of *kiremt* season in south Gondar Zone showed spatial and temporal variation during 1985-2014 CV at Wereta 4.9 %, cessation 3.8 % and length of growing period 9.9 %. The start of the rainy season shows increasing trend, Length of growing season (LGS) and end of rainy season shows decreasing trend (kelemu, 2021).

According to the Allen *et al*., (1998) in any region the crop growing season can have three characteristics, the beginning period, humid periods, and end of the growing period. The beginning of the growing period occurs when the rainfall is equal to half of the potential evapotranspiration which is considered to be the normal rainy season. The humid period is when the rainfall exceeds the potential evapotranspiration and end of the growth period is when the rainfall falls below half of the potential evapotranspiration, which marks the dry period. The start of the rainy season for both *belg* and *kiremt* could be easily achieved based on soil water balance model. The end of rainy season was defined by calculating of annual soil water balance. Start of rainy season (Onset) totally refers the start of rainfall though different researches are defining it in different ways. For example: (Stern *et al*., 1982) defined onset of a season as the date when the rainfall accumulated over 2 days is at least 20 mm and when no dry spell (exceeding 10 days) occurs within the following 30 days. Onset as the date in which 20 mm or more rainfall accumulated over three consecutive rainy days after a specified date with no dry spell greater than 7 days in the next 30 days (Tesfaye & Walker, 2004). Onset of *Kiremt* season was the date in which total rainfall of 20 mm or more recorded inconsecutive 3 days or more with no dry spell length of 10 days or more in the next 30 days should occur with an earliest starting day first of June (Segele & Lamb, 2005). According to the Allen *et al.*, (1998) the beginning of the growing period occurs when the rainfall is equal to half of the potential evapotranspiration which is considered to be the normal rainy season. Onset is quantified by the depth method ,it considers a cumulative rainfall depth that will bring the top 0.25 m of the soil profile to field capacity during a maximum of 4 days *(*Raes. *et al*., 2004).

End of rainy (cessation) season means withdrawal of rainy season. Like onset, end of rainy season is also defined differently by different authors. According to Tesfaye & Walker, (2004), cessation of rainy season is as the date when the available soil water content drops to 10 mm/m of the available water after months of September. End of rainy season is any date when water balance reaches zero after the first date of September for *kiremt* (Hadgu *et al*., 2013; Kassie *et al*., 2014). End of the growth period is when the rainfall falls below half of the potential evapotranspiration (Allen *et al.,* 1998). End of the rainy season was defined as any day when the soil water reaches zero with the assumption of a fixed average evapotranspiration of 5 mm per day and 100 mm/meter of soil water holding capacity (Stern *et al.*, 1982). Length of growing season (LGS) is the time from sowing to harvest or the time from planting to harvest. Length of *kiremt* and *belg* growing season was determined as the difference between the end and onset of rainy season (Stern *et al.*, 1982; Taye *et al.*, 2013; Hadgu *et al.*, 2013; Yemenu & Chemeda, 2013). Length of growing season is a period in days during a year when rainfall exceeds half the Evapotranspiration (ETO) plus the period required to Evapo-transpire water from the excess rainfall (Yemenu & Chemeda, 2013).

2.2. Historical Temperature trend and Variability in Fogera plain

In Ethiopian mean annual temperature rose by 0.28 °C per decade and annual maximum temperature rise by 0.2–0.28 °C per decade between 1960 and 2006 (Eshetu et al., 2014). Average annual minimum temperature has increased by about 0.25 °C every ten years in Ethiopia (Lemma *et al.,* 2013). Ethiopia is vulnerable to climate variability and change as it is reported by several researches (Alemayehu & Bewket, 2016; Birara *et al.*, 2018; Abeje & Alemayehu, 2019; Gebrechorkos *et al.*, 2019; Tegegne *et al.*, 2021; Rettie *et al.*, 2023). This is brought about due to the country's latitude position, complex topography, fragmented landscapes and rain fed agriculture system. Annual temperature have been increased in Addis Zemen Station (Getachew, 2018). Average annual temperature increasing in Wanzaye, Wereta and Addis Zemen (Dawit *et al*., 2019). Average temperature show increasing trend in Wereta and Addis Zemen station (Birara *et al*., 2018). Mean temperature had a generally increasing (Addisu *et al*., 2015). Trends of significant increase in minimum temperature in Wanzaye, Wereta and Addis Zemen station were observed (Dawit *et al.*, 2019). Average minimum temperature show increasing trend in Addis Zemen and Wereta (Birara et al., 2018). Addisu *et al.*, (2015) revealed that the mean minimum temperature had a generally increasing. Annual minimum temperatures were increasing in Lake Tana basin (Mengistu *et al.*, 2014; Mohamed & El-Mahdy, 2021). Minimum temperature in Addis Zemen station show increasing trend (Enyew *et al*., 2014; Meseret & Bhat, 2020). Minimum Temperature increase Wereta and Addis Zemen station (Dawit *et al*., 2019; kelemu, 2021).

Annual maximum temperature had a generally increasing in Lake Tana basin (Mengistu *et al*., 2014; Addisu *et al*., 2015; Mohamed & El-Mahdy, 2021). Average annual maximum temperature were increasing in Addis Zemen but decreasing in Wanzaye and Wereta station (Dawit *et al.*, 2019). Average maximum temperature show decreasing trend in Addis Zemen and show increasing trend in Wereta station (Birara *et al*., 2018). Maximum Temperature decrease in Wereta station but increase in Addis Zemen station (Enyew *et al.,* 2014; kelemu, 2021). Maximum and minimum temperature in Addis Zemen show increasing trend (Meseret & Bhat, 2020).

2.3 Projected trend and variability Rainfall and temperature in Fogera plain

2.3.1 General circulation models (GCMs)

General circulation models (GCMs) are the main tools for simulating historical and future climate patterns and extremes. These models are numerical representations of the Earth's climate system developed based on physical laws and empirical relations of processes in the ocean, atmosphere, and land surface (Raju & Kumar, 2020). Coupled Model Inter comparison Project (CMIP) is most widely applied for climate change studies (Touzé-Peiffer *et al.*, 2020). However, the outputs of these GCMs are associated with large inherent uncertainties due to model assumptions, initial boundary conditions, resolution, parameterization, model structure, calibration and others (Jose & Dwarakish, 2022). They have a horizontal resolution of between 250 and 600 km, 10 to 20 vertical layer in the atmosphere and sometimes as many as 30 layers in the oceans, whereas RCMs have a horizontal resolution of about 50 km or less. Uncertainties can be minimized through evaluation and selection of appropriate GCMs before applying output models for climate-related studies (Shiru & Chung, 2021). Various studies have assessed the performance of CMIP6 models in reproducing the mean rainfall over Ethiopia (Alaminie *et al.*, 2021; Alamineh *et al.*, 2022; Terefe *et al.*, 2023; Afrasso *et al.*, 2023; Omay *et al.*, 2023). Climate predictions using recent and high-resolution climate models are becoming important for effective decision-making and for designing appropriate climate change adaptation and mitigation strategies (Alaminie *et al*., 2021). The relevance and applicability of climate models at a local-scale for the study of climate change are limited because the raw GCM output is not capable of representing climate variables of particular regions, it needs downscaling.

To improve the spatial resolution, climate models should be downscaled by applying either statistical (Tavakol-Davani *et al*., 2013) or dynamical downscaling techniques (Chen & Zhang, 2010). Both statistical dawn scaling and dynamical downscaling are dependent on GCM boundary forcing, domain size and location. Dynamical downscaling techniques use local physical factors such as topographic features nested within GCM to produce local or regional climate model (RCM) at a fine-scale resolution, usually 50 km. Endris *et al*., (2013) employs regional climate models (RCMs) for limited regions with boundary conditions from GCM simulation. Statistical downscaling develops a statistical relationship between local-scale climate variables and large-scale GCM out puts

(Gebrechorkos *et al.*, 2019; Kaini *et al*., 2020). Besides, Statistical downscaling is simple, requires fewer resources and is computationally efficient. It is suitable to achieve spatial downscaling and bias correction of multiple models, and their resolution is higher than Dynamical downscaling. The statistical downscaling method establishes statistical relationships between historical climate records at coarse resolutions and fine resolutions to interpolate from coarse model outputs to finer resolutions which mean large-scale climate information and regional variables.

IPCC fifth assessment report (AR5) featured four Representative Concentration Pathways (RCPs) that examined different possible future greenhouse gas emissions. RCP2.6, RCP4.5, RCP6.0 and RCP8.5 coupled model inter comparison phase five (CMIP5) have been upgraded to new versions in coupled model inter comparison phase sixe (CMIP6) shared socioeconomic pathways (SSPs) SSP1-2.6, SSP2–4.5, SSP4-6.0 and SSP5-8.5 respectively (Maloney et al.,2014).

SSP1 (sustainable development) low for mitigation and adaptation sustainable development proceeds at a reasonably high pace, inequalities are lessened, technological change is rapid and directed toward environmentally friendly processes, including lower carbon energy sources and high productivity of land.

SSP2 (middle of the road) moderate an intermediate case between SSP1 and SSP3 perhaps can be viewed as business-as-usual.

SSP3 (regional rivalry) high for mitigation and adaptation unmitigated emissions are high due to moderate economic growth, a rapidly growing population, and slow technological change in the energy sector, making mitigation difficult. Investments in human capital are low, inequality is high, a regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity.

SSP4 (inequality/road divided) high for adaptation and low for mitigation. There is a strong division between people living at higher and lower development levels, both between countries and between regions and communities. World mixed with relatively rapid technological development in low carbon energy sources. In key emitting regions, leading to relatively large mitigate capacity in places where it matters most too global emissions. However, in other regions development precedes slowly, inequality remains high, and economies are relatively isolated, leaving these regions highly vulnerable to climate change with limited adaptive capacity.

SSP5 (fossil –fueled development) is characterized by high challenge to mitigation and low challenges to adaptation (Riahi *et al.*, 2017; Pörtner *et al*., 2022). In the absence of climate policies energy demand is high and most of this demand is met with carbon-based fuels. Investments in alternative energy technologies are low and there are few readily available options for mitigation. Nonetheless, economic development is relatively rapid and itself is driven by high investments in human capital. Improved human capital also produces a more equitable distribution of resources, stronger institutions, and slower population growth, leading to a less vulnerable world better able to adapt to climate impacts.

2.3.2 Projected trend and variability of Rainfall and Temperature

In Ethiopia, a study conducted by Arndt et al., (2011) showed decreasing *kiremt* and *belg* seasons' rainfall by 20% and 5-6%, respectively by 2080. The trend and variability of precipitation have been inconsistent in upper Blue Nile in 2050-2080 under RCP 4.5 scenarios with the baseline period of 1976-2005 (Tariku *et al.*, 2021). Annual rainfall 2080, projections did not show consistent trend over the basin, it increases in the northern and central parts of the basin and decrease in some parts of the basin (Getachew & Manjunatha, 2021). Annual mean rainfall over Gilgel Abay river in the Tana Lake basin may decrease in the first 30 years by during (2010-2040) but increase during the next two 30 years (2070-2100) (Dile *et al.*, 2013). Rainfall is decreasing at Rib catchment in Fogera plain 2041–2070 and 2071–2098 with a base line period 1976–2005 (Desalegn *et al.*, 2016). Future temperature is shown to increase in Ethiopia, mean annual temperature has risen by 1.3 ◦C between 1960 and 2006 and is projected to increase up to 1.8 ◦C by 2050 and 3.7 ◦C by the end of the century, under a high-emission scenario RCP8.5 (Zegeye, 2018). Annual temperature across Ethiopia could be 0.7–2.3 °C and 1.4–2.9 °C in the 2020 and 2050 respectively (Conway & Schipper ,2011). Daily maximum and minimum temperature of the upper Blue Nile is projected to rise by around 1.35-2.38 °C and 1.72-2.74 °C in 2050-2080 under RCP 4.5 scenarios with the baseline period of 1976-2005 (Tariku et al., 2021).

Future climate change at the Lake Tana basin level showed variability of rainfall and an increase in temperature(Adem *et al.*, 2016). Maximum and minimum temperature will be increased in 2080s unlike temperature, rainfall results showed decreasing trend in all projected years (Ayalew *et al.*, 2012). (Getachew & Manjunatha, 2021) indicated that maximum temperatures are expected to increase from 1.38 °C to 3.59 °C under RCP 4.5 scenarios by 2080s, while minimum temperatures are expected to increase up to 5.92 °C under RCP 8.5 by the end of the 21st centuries in Lake Tana basin. Temperature showed an increasing trend at Ribb catchment, in Fogera plain 2041–2070 and 2071–2098 with reference period 1976–2005 (Worku et al., 2022). Temperature showed an increasing trend in the Lake Tana basin for the near long-term periods (Alaminie et al., 2021).

2.4 Climate Variables and Rice Yield

Crop yield and growth is strongly associated with weather conditions Worldwide, more than 50% variability in crop yield observed only due to climate variation (Ray *et al.*, 2015). The variation in temperature and rainfall is negatively impacting crops, resulting in a decline in the agricultural yield (Ullah, 2017). Zaied & Cheikh,(2015) found that an increase annual temperature decreases both date and cereals output, while cereals production is positively affected by the annual rainfall. Precipitation has a positive and significant effect on cereal crops production both in the long and short runs, while temperature change has a significant negative effect (Asfew & Bedemo, 2022). Changes in temperature and precipitation and climate extreme events like drought and flood have a direct impact on crop yield. Many researchers (Getachew, 2017; Addisu Kebede, *et al.*, 2019; Molla *et al*., 2020; Asfew & Bedemo, 2022) have conducted studies on impact of climate change on yield of cereal crops in Ethiopia. In Ethiopia, when compared to other crops production cereal production is a leading form of agricultural practice. Out of the total grain crops area 81.19% hectares of land were under cereals with a production contribution of 88.36% of the total grain in the country which is higher than the percentage shares of other crops such as pulses 12.9 % and oilseeds 5.9% (CSA, 2021). Crop yield will decline by 4.21% for each 1 °C rise in maximum temperature and increase by 0.43% for each 1% rise in rainfall (Qin *et al.*, 2023).

Rice is grown in almost all continents except Antarctica where plant growth is impossible due to low temperature (Lou *et al*., 2012). Rice response to temperatures varies according to different stages of its biological development. Rice plants take around 3–5 months to grow from seeds to mature plants, depending on the variety and environmental conditions. They undergo three general growth phases: vegetative, reproductive and ripening. Rice plants during their early stage of growth and development(vegetative stage), which takes 60 days, need only a little amount of water, so the two consecutive months that have less rainfall must be chosen. During their reproductive stage, which takes 30 days, the rice plants need larger amount of water up to the flowering stage so this phase should be undertaken in a month where in the rainfall count is high. The ripening stage, which takes 30 days, is from milk, dough, yellowish and full ripening of grains, only a little amount of water is needed by the rice plants. No standing water is needed after the grains have become yellowish in color. Normally no more water is needed when the ripened grains of the rice plants are about to be harvested. The draining of the farm land is usually done ten days before harvesting. The month that has less rainfall is suitable for this phase. Generally rice needs 450 - 700 mm of water/growing period 90 -150 days (FAO, 2020). Temperature is an important factor which significantly affects rice growth and development, minimum and maximum temperature ranges of each growth stage for rice are: germination (16–45 °C), seedling rise (12–35 °C), rooting (16–35 °C), panicle heading (15–30 °C) and ripening (21-23 °C) (Luo *et al.*, 2018). Rice grain yield and quality is negatively affected by high temperature stress at reproductive or grain filling stages (Fahad *et al.*, 2019).

1% rise in rainfall leads to 22% increase in rice yield while 1% increase in temperature reduced 4% rice production in Nigeria (Nwalieji & Uzuegbunam, 2012). Mohammed *et al*., (2022) also described that rainfall increase from 5 to 15% during September–October showed a negative impact on the rice yield for the heading, flowering, and ripening stages. Even with sufficient rainfall, increasing temperatures contribute to reduced yields (Luhunga *et al.*, 2017). Increasing temperatures has been identified as the main yield-reducing factor (Khanal *et al.*, 2024). 1 °C rise in temperature decreases rice yield by roughly 4% in the rice production areas (Yang et al., 2018). High minimum and maximum temperature reduced the number of rice plants, increased the tiller rate, and shortened the growth period that reduced rice yield (Sridevi & Chellamuthu, 2015). Excessive high temperature will increase the risk of heat stress contributing to the reduction of pollen, thus affecting the process of pollination and fertilization (Chen *et al.*, 2016; Bai *et al.*, 2016; Chen & Chen, 2018; Zafar *et al.*, 2018). Temperatures above 28 °C can cause massive reductions in rice yield by constraining the photosynthesis of rice and reducing pollen production (Wei *et al*., 2014; Chen & Chen, 2018). Increasing night temperature has been significantly reducing the rice yield (Khanal *et al.*, 2024). Rice grain yield and quality is negatively affected by high temperature stress at reproductive or grain-filling stages (Bahuguna & Jagadish, 2015). Minimum temperature had a large and positive impact where as higher maximum temperature had negative impacts on rice yield (Chen *et al*., 2014). Rainfall have positive, while minimum and maximum temperature show negative correlation (Adhikari *et al.*, 2017, Shailesh Adhikari ,2020). Annual rainfall amount, LGP and number of rainy days show positive correlation, rainfall onset date was negatively correlated with rice yield in Fogera plain (Molla *et al.*, 2020). Rainfall, minimum and maximum temperature will show positive correlation with rice yield increasing trend with a trend coefficient of 2.9 quintals per hectare per year for Addis Zemen station in Fogera plain (Getachew, 2017).

Rice is the primary staple crop after wheat (*Triticum aestivum*) and is the source of 50% calories for the almost 50% population of the world and its demand will increase by 28% in 2050 (Hussain *et al.*, 2020). Rice cultivation is the source of earning for approximately 145 million people of the world and covering 165 million hectare which is about 11% of agriculture land. Rice production in sub-Saharan Africa has been growing at a rate of about 6% over the last decade (FAO, 2019). The production increase has been due to land expansion (70%) as well as an increase in productivity (30%). 100–110% increase in crop yield and production is needed in order to feed whole population by 2050 (Kontgis *et al.*, 2019). In Ethiopia, rice is recognized as a “millennium crop” with scopes for tall work creation potential and note worthiness on nourishment security particularly in places where other nourishment crops like teff (*Eragrostis tef*), maize (*Zea mays*), don’t do well. Rice production in Ethiopia covers 48,418 hetare of land by about 150,041 households producing 1,360,007 quintals of grain yield (CSA, 2017). The average rice productivity in Ethiopia is estimated at 2.8 t/ha (Tilahun *et al.*, 2013),which is much lower than the World‘s average productivity of 4.4 t/ha. The major rice production, which is found in the North-western part of Ethiopia (Amhara Region) accounts for about 75% of the area coverage of about 39,830 hectare and 80% of the production 119, 384.56 tons, other regions contributed 25% of the area coverage 13,276.75 hectare and 20% of the rice production 29, 846.14 tons (CSA, 2018). The potential of rice production area in the country is estimated about 39,354,190 hectare out of this land 5590895 hectare is more suitable, 2491629 hectare is suitable and 8852666 hectare is moderately suitable. Rice grow at the present is 81.2% is rain fed low land, 18.6% rain fed upland and 0.2% is irrigated (Ethiopian institute of agriculture research , 2020). Production increase from 7194 tons in 2009 to above 165000 tone in 2019 (CSA, 2020).

2.4.1 Future climate and rice production

Climate change that may continue to affect rice production in sub-national levels in the world's top three rice exporters namely Thailand, Vietnam and India with a period of 2030,2050 and until the end of the 21st century (Paul *et al.*, 2016). Increase in rice yield of individual and large-scale farming under RCP4.5, ranging from 1.3 to 29.8% and 2.0 to 30.8%, respectively, whereas it fluctuates from 11.7 to −29.0% and 8.3 to −20.8% under RCP8.5 for individual and large-scale farming, respectively (Nathsuda et al., 2020). Wetland rice production is projected to decrease by about 3% (1%–4%) at 2030 and 6% (3%–8%) at 2090 compared to rice yield without climate change RCP4.5 scenario (Muhamad, 2021). Projections of climate change indicated a decrease in the length of the growing period through the shifting of onset and cessation dates over different regions in Ethiopia (Hadgu et al., 2013; Kassie et al., 2014; Gardi, 2022). The shortening of the growing period with increasing temperatures has been identified as the main yield reducing factor (Gardi, 2022).

2.4.2 Crop yield predicting Models

Two main techniques are used to evaluate the effect of climate change on yields: 1) crop growth models and 2) regression analyses. Crop growth models are widely used and produce precise crop yield responses to weather events. However, crop growth models require daily weather data and are calibrated under experimental conditions. Alternatively, regression analyses allow the quantification of weather changes on crop yields in an actual cropping context (Blanc,2012). Correlation, regression, and simulation models have been widely used to determine the climate crop yield relationship.

The correlation coefficient is a statistical measure of the strength of the relationship between the two variables. The values range between -1.0 and 1.0 a calculated number greater than 1.0 or less than -1.0 means that there was an error in the correlation measurement. Correlation of -1.0 shows a perfect negative correlation, while a correlation of 1.0 shows a perfect positive correlation. Correlation of 0.0 shows no linear relationship between the movement of the two variables (Poudel, & Shaw, 2016). Long-term good quality datasets of yield and agro meteorological conditions are required to develop yield-forecasting statistical models. The advantage of this statistical base approach is that they basically account for a wide range of mechanisms investigate the individual input variables that are capable of influencing crop yields while maintaining all other variables constant. Regression models that use time series data on both climate variables and yields are more efficient of providing accurate estimates of the changes in crop yield as a result of changes in climate variable. These models fit the direct relationship between meteorological parameters and crop yield and can be considered to have good efficiency and satisfying output (Mathieu & Aires, 2018).

CHAPTER 3 MATERIAL AND METHOD

3.1 Descriptions of the study area

This study was conducted in Fogera plain, Lake Tana Sub basin Ethiopia, which is located between 11°40' N and 12°10' N latitude & 37°30' E and 38°00' E longitude. Libo Kemkem District has 31 rural kebele administrations out of which 18 kebeles are rice producers. The district has 46,604 farm households, of which 42,014 are male-headed and 4,590 are female-headed households. Farmers participating in rice farming are 17,384, of which 17,006 are male-headed and 378 are female-headed households. Fogera District has 33 rural kebele administrations, of which 27 kebeles produce rice. The district has 47,440 households, of which 40,918 are male-headed and 6,522 are female-headed households. The total number of farm households participating in rice farming was 40,968, of which 40,579 were male-headed and Dera wereda have 36 kebeles of which 5 kebeles produce rice (Alemu *et al*., 2018).

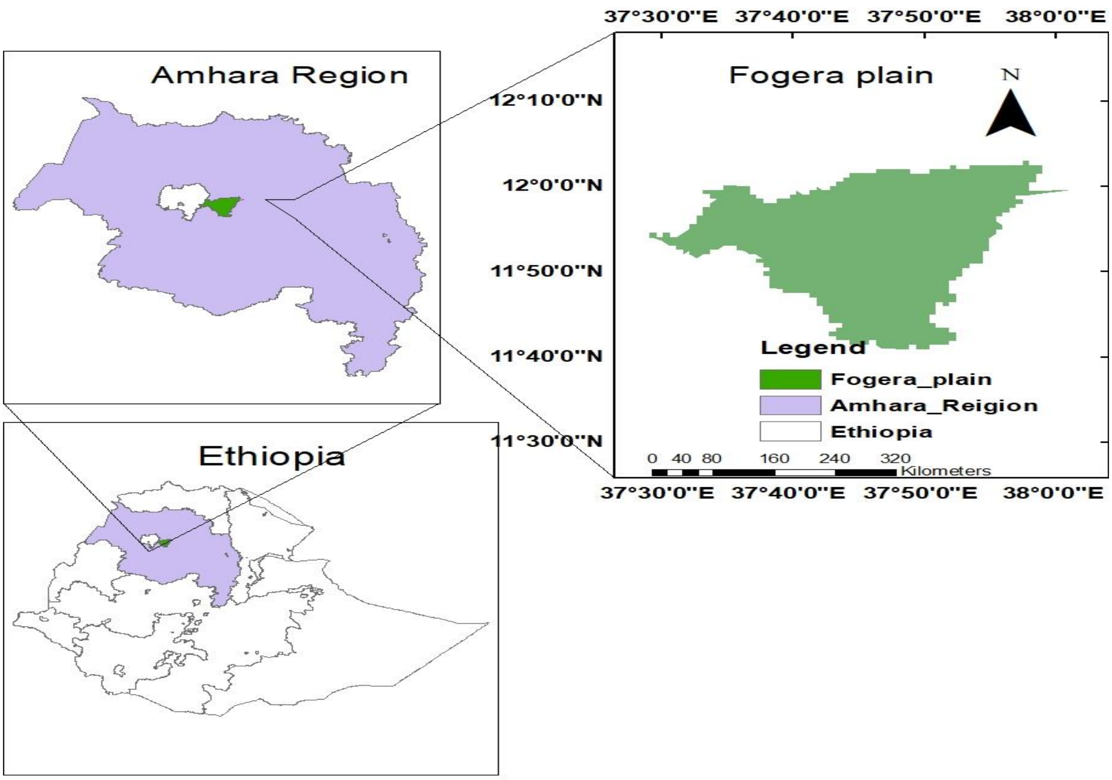

Figure 3.1. Location map of study area

3.2 Research approach

This study employed the quantitative research approach whereby secondary time series data were utilized. Quantitative research approach refers to a research method where measurable numerical data are collected and analyzed to make predictions and test causal relationship between variables.

3.3 Data types and sources

3.3.1. Climate data

This study was done based on climate data (rainfall and temperature). Temperature (°C) and rainfall (mm) records from 1993 to 2022 were collected for three weather stations of Fogera plain, with a reasonably good geographic distribution to cover the study area. The stations were chosen based on the length of the record period and the completeness of the data. Daily rainfall, maximum, and minimum temperature data were collected from Ethiopian Meteorological institute (NMI) Bahir Dar branch. The seasonal and annual total rainfall, maximum, and minimum temperature were then calculated from the daily data of those stations.

Table 3.1. Description of weather stations selected for the study in Fogera plain

Station name	Lat. (oN)	Long (oE)	Alt. (M)	Data record years	Missing data (%)		
					Rainfall	Temperature	
						Maximum	Minimum
Addis Zemen	12.1	37.87	1936	1993-2022	9.9	-	-
Wereta	11.92	37.69	1819	1993-2022	8	8.9	9
Wanzaye	11.78	37.68	1830	1993-2022	9.8	5.3	5.3

3.3.2 Seasonal rainfall characteristics (onset, cessation and Lgp) data

Onset date of rainy season was determined by (Allen *et al*., 1998) the beginning of the growing period occurs when the rainfall is equal to half of the potential evapotranspiration. End of the growth period is when the rainfall falls below half of the potential evapotranspiration (Allen *et al*., 1998). End of the rainy season was defined as any day when the soil water reaches zero with the assumption of 100 mm/meter of soil water holding capacity (Stern *et al.*, 1982). According to (Allen *et al*., 1998) lengths of growing period were determined by the rainfall data that are greater than half of potential evapotranspiration (end of the growth period- onset date of rainy season).

3.3.3 Future climate data and Climate Model selection

Future climate maximum temperature , minimum temperature and rainfall data were derived from daily scale meteorological data output from SSP1-26 (combination of SSP1 and Rcp2.6),SSP2-4.5 (combination of SSP2 and Rcp4.5) and SSP5-8.5 (combination of SSP5 and Rcp8.5) of the CMIP6 (https://esgfnode.llnl.gov/projects/cmip6/ accessed on 17 April 2023), it is Netcdf file so it is both extracted, correct the bias and projected by CMhyd software (Rathjens *et al.*, 2016). For two future periods 2025–2055 and 2056–2086, MRI-ESM2-0 climate model selected for temperature and BCC-CSM-2MR climate model selected for precipitation based on their highest performance in UBNB (Abay) (Alaminie *et al.*, 2021). Bias correction method (linear scaling, delta change, power transformation, distribution mapping, local intensity scaling and variance scaling) selected from CMhyd software based on their highest correlation with station data.

3.3.4 Crop data

The rice production and productivity data would obtain from three districts of the Fogera plain .Data was collected from Dera and Fogera 1993-2022 and Libo kemkem district 2009-2022 agriculture office annual report.

3.4 Method of data analysis

3.4.1 Data quality checking and control

The data obtained from rainfall gauge may have a shortage breakage in the records because of instrument failure or absence of the observer. Like daily precipitation amounts less than zero and outliers daily maximum temperature is less than the daily minimum temperature and non-recording days data was checked before it was used for further analysis by visual inspection then write missing data. There are methods used to fill the missing data of weather stations. These are arithmetic mean, normal ratio method and inverse distance weighing methods. Arithmetic mean method can be used to fill in missing data when normal annual precipitation is within 10% of the gauging station for which data are being reconstructed. The normal ratio method is used when the normal annual precipitation at any of normal index station differs from that of precipitation by more than 10%. In the absence of normal annual rainfall for the stations; inverse distance weighing can be used to fill the missing data. Arithmetic method used for this work. By taking neighboring station average and taking the preceding and succeeding day average.

3.4.2 Potential evapotranspiration analysis

Potential evapotranspiration (PET) is analyzed by two methods (Penman Montez (PM) and Hargreaves's). Potential evapotranspiration (PET) was analyzed by standardized precipitation evaporation index (SPEI) packages in R software (PET) (Allen *et al.*, 1998). However, the Penman Montez (PM) method requires full meteorological data which is difficult to get it. Estimation of (PET) needs measurements of many weather variables such as atmospheric pressure, wind speed, air temperature, net radiation and relative humidity but these weather variables are not easily obtainable from practical measurements in weather stations because weather stations in study area are class III meteorological stations that can collect only air temperature and rainfall and class IV stations that can collect only rainfall. Thus, the PET can be estimated using Hargreaves (Hargreaves & Samani, 1985) method which has a very similar output as PM (Beguería *et al.*, 2014). Hargreaves's method needs only precipitation, minimum, maximum temperature, and latitude (extraterrestrial radiation). Therefore, in this study the Hargreaves technique was used to calculate the PET. Hargreaves and Samani (HS) method

PET=0.0023*(Tmean+17.8) (√Tmax-Tmin) Ra)………. ……Equation 4

Where: PET= potential evapotranspiration of Hargreaves method (mm/day), Ra =the extraterrestrial radiation (mm/day), calculated theoretically as a function of latitude, T mean = the average temperature (°c), Tmin and Tmax= minimum and maximum temperature (°c) respectively.

3.4.3 Methods of Rainfall and Temperature Trend and Variability Analysis

Several methods have been designed to analyze the rainfall and temperature trend and variability. According to (Asfaw et al., 2018) variability analysis involves the use of Coefficient of Variation (CV), percentage departure from the mean (Anomalies), and Precipitation Concentration Index (PCI), while trends can be estimated through different parametric and non-parametric tests only for consistent data. Among the non-parametric techniques, the Mann Kendall (MK) test is the most commonly used test to assess monotonic trends (increasing or decreasing) in series of environmental data, climate data, or hydrological data (Asfaw et al., 2018) Hence, various studies employed the Mann–Kendall test to evaluate the presence of trends in both annual temperature and rainfall data (Gebrehiwot & Simhadri, 2015; Esayas *et al.*, 2019). Further, the Sen's slope estimator (SSE) is used to estimate the magnitude of the trends in the time series data (Esayas et al., 2019).

Coefficient of variation (CV) was also calculated by dividing the standard deviation of the event to its mean. Coefficient of variation (CV) was computed as:

$$CV=\left(\frac{\delta}{\times -}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{Equation 1}$$

Where, CV = coefficient of variation; X = average long-term rainfall or temperature over the given decade and δ= the standard deviation.

Based on CV the degree of variability was classified as less variable, for CV< 20%, as moderately variable for CV from 20% to 30%, and as high variable for CV > 30%.

percentage departure from the mean (SAI) , value as: extremely wet if, SRA≥2very wet if 1.5≤ SRA≤ 1.99, moderately wet if1≤ SRA≤ 1.49 , near normal if,-0.99 - 0.99≤moderately dry if -1≤SRA≤-1.49 , and severely dry if-1.5≤SRA≤-1.99and extremely dry if≤-2 (Matewos, 2019). This index is used to examine the nature of the variability and enables the determination of the dry and wet years in the record.

$$SAI\ (z) = \left(\frac{x-\mu}{\delta}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 2}$$

Where, *Z* = standardized rainfall or temperature or crop anomaly; x = crop growing seasonal rainfall total or mean crop growing season temperature of a particular year was the mean crop growing season rainfall over a period of observation and $\boldsymbol{\delta}$ = the standard deviation of crop growing season rainfall over the period of observation.

Precipitation concentration index (PCI %) according to the National Meteorological Agency of Ethiopia (NMSA 2001), three seasons, namely, *belg* season (March to May), *bega* season (October to February) and *kiremt* season (June to September) exist in Ethiopia. Therefore, PCI were determined based on annual and seasonal time scales for all stations

PCI=[$\frac{\sum_{i=1}^{12} p2}{(\sum_{i=1}^{12} p)2}$]*100………………………….…Equation 3

Where P = rainfall amount of the ith month, and Σ = summation over the 12 months PCI <10 Uniform distribution of precipitation (Low concentration),11–16 Moderate distribution of precipitation (Moderate concentration),16–20 Irregular distribution of precipitation and >20 Strong irregularity of precipitation distribution.

Modified Mann Kendall (MMK) test is the most commonly used test to assess monotonic trends (increasing or decreasing) in series of environmental data, climate data or hydrological data (Asfaw *et al*., 2018).

The MMK test statistic is given as:

S=$\sum_{k=1}^{n-1}\sum_{j=k+1}^{n} (Xj - Xk)$………………………..Equation 5

Where xk and xj are the sequential data values of the time series in the years i and j (j > k) and n is the length of the time series. Positive S value indicates an increasing trend and negative value indicates a decreasing trend in the data series. The sign function is given as:

$$sign(xj - xk) = \begin{cases} +1, \ldots\ldots\ldots. if(xj - xk) > 0 \\ 0, \ldots\ldots\ldots. if(xj - xk) = 0 \\ -1, \ldots\ldots\ldots.. if(xj - xk) < 0 \end{cases}$$

If the value is positive, it indicates increasing trends, while negative values show decreasing trends 0 which signifies their is no trend.

Sen.'s slope estimator and percentage change, if a linear trend is present in the time series, the true slope can be estimated using a simple non-parametric test known as Sen's slope method. Sen's slope estimator (SSE) is used to estimate the magnitude of the trends in the time series data (Yayeh & Filho, 2017; Esayas et al., 2019). Sen, (1968) developed the non-parametric procedure for estimating the slope of trend in the sample of N pairs of data.

Ti=$\frac{Xj-Xk}{j-k}$ ………………………………………………. Equation 6

For i=1, 2, 3…N, Xj and Xk represent the data value at the time-steps 'j' and 'k' with 'j' correspondingly greater than 'k'.

Percent change is calculated by the following formulae:

%Change = ($\frac{\beta * Length\ of\ perod}{mean}$) …………………Equation 7

Where β is Sen's slop

3.4.4. Projecting future rice productivity

Furthermore, depending on the objective of the research, simulation, and regression models can be used to estimate the effects of climate variables on crop productivity and yield (Dhurandher *et al.*, 2024). Various studies used regression models to estimate climate variables impacts on crop yields (Adamgbe & Ujoh, 2013; Maharjan & Joshi, 2013; Alemayehu & Bewket, 2016; Poudel, & Shaw, 2016). Multi-linear regression analysis can be used to assess the impact of climate variables precipitation and temperature on crop yields such as Maize, Rice, Wheat, and Millet (Poudel, & Shaw, 2016). In addition to the use of the exact statistical method of analysis, it is recommended to consider more than 20- 30 years to study the impact of climate variables on yields of the food crops (Maharjan & Joshi, 2013).

Pearson correlation coefficient (r) analyses was used to analyze the correlation between yield (qt/ha) of rice crop with characteristics different rainfall and temperature variables. Correlation coefficient (r) value close to +1 were interpreted as indicators of a strong positive correlation, and a correlation coefficient close to -1 were interpreted as indicators of a strong negative correlation while a correlation coefficient of 0 were interpreted as indicators of no correlation (Poudel, & Shaw, 2016). Correlation coefficient is performed using the Equation, in which x represents the independent variable and y represents the dependent variable.

$$\mathbf{r} = \frac{\sum(x-\bar{x})(Y-\bar{Y})}{\sqrt{\sum(x-\bar{x})^2(Y-\bar{Y})^2}} \text{ -------------------------------------- Equation 8}$$

Where $\bar{x}$ and $\bar{Y}$ represent the sample mean of x and Y respectively

Regression analyses allow the quantification of weather changes on crop yields in an actual cropping context (Blanc, 2012). Regression analysis is a statistical technique for estimating the relationships between a dependent variable and independent variables. It is well-known and as such, it is extensively used in forecasting future impacts of climate change on crop yields (Poudel, & Shaw, 2016). Regression equation for rice productivity

Productivity =b0 + b1X1 + b2X2 + b3X3 + b4X4 + X5+ eror…………………Equation 9

X1: *kiremt* maximum temperature, X2: September maximum temperature (°C), X3: *Kiremt* rainfalls (mm) X4: length of growing season (day), X5 onset of growing season (day). b0: Intercept coefficient b1, b2,--b5: Slope coefficients.

3.4.5 Rice productivity Model calibration and validation

1993-2022 observed rice productivity data would obtain from Fogera and Libokemkem district agricultural office and in Libokemkem district agricultural office annual report 2009-2022. Regression equation derived with historical climate and crop data for each station with period 1993-2014 and then check the validity by the period 2015-2022 for the two station and for Addis Zemen station from 2009-2018 as calibration, 2018-2022 for validation. Then simulated rice productivity data and actual (observed) rice productivity for this period were evaluating performance by correlation to ensure that the method was good or not. After that evaluating performance and generate productivity data for near term 2025-2055 and long term 2056-2086 period.

CHAPTER 4 RESULT AND DISCUSSION

4.1 Trend and variability of rainfall and temperature Characteristics in Fogera plain

4.1.1 Seasonal, annual rainfall and Rice Crop growing season trend

The result of the MMK test was applied to analyses the mean annual and seasonal rainfall trend for the period of 1993–2022 for all the three stations in Fogera plain. Similarly, Sen.'s slope and percentage change were used to examine the magnitude and change of the variables. The results of the MMK trend, Sen.'s slope and percentage change of rainfall are given in Table 4.1. The annual and seasonal trend and the change rate vary widely from place to place. The trend indicates the mean annual and seasonal rainfall increase (positive trend) in Wereta and Addis Zemen, *kiremt* season rainfall has been increasing by 11 mm and 142 mm per decade and also the annual rainfall has been increasing by 14.3 and 175 mm per decade at Wereta and Addis Zemen stations respectively.

Table 4.1. Trend of annual and Seasonal rainfall for three stations in Fogera plain

Station	Season	Kendall Tau	Sen's slope	P-value	Change% (mm/30 Year)
Addis Zemen	Annual	0.23	17.5	0.01	38
	Kiremt	0.17	14.2	0.08	36
	Belg	0.14	2.4	0.02	74
	Bega	0.22	1.8	0.00	58
Wereta	Annual	0.04	1.4	0.53	2.8
	Kiremt	0.37	1.1	0.6	2.8
	Belg	0.11	2	0.05	27.5
	Bega	0.1	0.3	0.14	7.5
Wanzaye	Annual	-0.17	-4.7	0.00	-9.7
	Kiremt	-0.21	-4.9	0.00	-11.9
	Belg	-0.08	-1.1	0.15	-26.6
	Bega	1.1	0.08	0.2	2.4

. On the other hand reduction (negative trend) annual and *kiremt* rainfall shows statistically significant decreasing trend in Wanzaye (at -4.73 mm/year and -4.9 mm/year) at the 5 % level of significance. this finding is similar with (Addisu *et al*., 2015; Birara *et al.*, 2018; Dawit *et al.*, 2019). Generally in Wereta station all seasonal and annual rainfall increase insignificantly but in Addis Zemen station increase significantly except *kiremt* season. This result is confirmed with (Addisu *et al.,* 2015) who reported a non-significant trend of annual and seasonal rainfall totals of different stations in upper sub basin of Lake Tana.

During the base period (1993-2022), decreasing trends in length of growing period in kiremt growing season were observed at three studied stations Wanzaye, Wereta and Addis Zemen (Table 4.2). Increasing trends in start date of season (SOS) of the kiremt growing season were observed at three studied stations Wanzaye, Wereta and Addis Zemen.

Table 4.2. Trend of rice growing season rainfall characteristic's in Fogera plain.

Station	rainfall characteristics	Kendall's Tau	Sens's slope	P Value	Trend (day/decade)
Wanzaye	Onset	0.23	0.16	0.00	1.60
	Lgp	-0.08	-0.10	0.24	-1
	Cessation	-0.14	-0.10	0.06	-1.00
Wereta	Onset	0.35	*0.38*	0.00	3.8
	Lgp	-0.23	-0.33	0.00	-3.30
	Cessation	0.00	*0.00*	1.00	0.00
Addis Zemen	Onset	0.17	*0.24*	0.07	2.40
	Lgp	-0.15	-0.25	0.01	-2.50
	Cessation	0.06	0.09	0.30	0.90

Though, the observed onset trends were insignificant at Addis Zemen but statistically significant at both Wanzaye and Wereta stations, the positive signs are indications of a tendency of late entrance kiremt growing season during base period whereas end of season shows the negative signs are indications of a tendency of early ends of kiremt growing season during base period. However, (Hadgu *et al.*, 2013) found significant forward shifting in the start date (indicates late entrance) of the kiremt growing season at three of four stations under his study in northern part of Ethiopia. On the other hand, in the present study increasing trend in end date (EOS) of the kiremt growing season were observed at

Addis Zemen conversely, decreasing in Wanzaye and no trend was found at Wereta during the study period**.**

4.1.2. Observed Temperature Trends in Fogera plain

Analysis of historical maximum temperature data (1993-2022) from the ground gage stations revealed that both annual and seasonal maximum temperatures in all stations had an increasing trend (Table 4.3). But in Wereta station the *kiremt* maximum temperature had decreasing trend. Accordingly, mean annual maximum temperature had increased by 0.07 °C, 0.003 °C and 0.07 °C per year at Wanzaye, Wereta and Addis Zemen stations respectively. Annual maximum temperatures in Wereta are insignificant at $p = 0.05$ but annual maximum temperatures in Wanzaye and Addis Zemen are statistically significant.

Table 4.3. Trend of temperature (1993-2022).

Station	Season	Maximum temperature				Minimum temperature			
		Kendall Tau	Sen's slope	P Value	Δ% in30 Year	Kendall Tau	Sen's slope	P value	Δ% in30 Year
Addis Zemen	*Belg*	0.3	0.11	0.01	10	0.128	0.03	0.09	7
	Kiremt	0.2	0.03	0.01	3	0.08	0.03	0.4	7
	Annual	0.3	0.07	0	7	0.003	0.003	1	0.8
Wereta	*Belg*	1.8	0.05	0.07	5	0.5	0.2	0	41.3
	Kiremt	-0.23	-0.04	0	-4.6	0.6	0.17	0	36
	Annual	0.03	0.003	0.8	0.3	0.6	0.2	0	44
Wanzaye	*Belg*	0.19	0.08	0.12	8	0.54	0.11	0	22.8
	Kiremt	5	0.12	0	14.3	0.44	0.06	0	12.7
	Annual	0.45	0.07	0	7.6	0.54	0.08	0	18.3

These results are consistent with earlier studies by (Birara et al., 2018; Dawit et al., 2019; kelemu, 2021) that found a warming trend in the annual maximum temperature. The results obtained in Wanzaye and Wereta which clearly indicate that maximum temperature trends over the studied period are not consistent between seasons. In this regard, *kiremt* season maximum temperature had increased significantly by 0.12°C and 0.03°C per year at Wanzaye and Addis Zemen stations respectively. Analysis of historical minimum temperature data (1993-2022) from the ground gage stations revealed that annual and seasonal minimum temperatures in all stations had an increasing trend (Table 4.3). Most studies concluded that the minimum temperature has been increasing (Addisu *et al.,* 2015; Asfaw *et al.,* 2018; Birara *et al.,* 2018; Dawit *et al*., 2019; kelemu, 2021). In present study, the rate of the minimum temperature change was higher than the maximum temperature change in all stations. The minimum temperature incremental increase is more evident than that of the maximum (Mohamed & El-Mahdy, 2021).

4.1.3 Variability of rainfall Characteristics (Coefficient of variation (CV %) Precipitation concentration index (PCI), Standard rainfall anomaly (SAI) and Rice crop growing season variability)

Table 4.4 shows that the study area received mean annual rainfall ranging from 1384.3 mm to 1519.5 mm with a mean of 1453.667 mm rainfall and CV of 20.8%; CV varied from 16-25.4%. At the seasonal level, kiremt rainfall varied from 1182.2-1231.5 mm with mean of 1202.833 mm.

Table 4.4. Annual and seasonal rainfall (mm) coefficient of variation (CV %)

Rainfall (mm)		Wanzaye	Addis Zemen	Wereta	areal mean
Belg	Mean	124.3	96.9	218.3	146.5
	CV	67.1	84.1	40	63.7
	CT	8.5	7	14.4	10
kiremt	Mean	1231.5	1194.8	1182.2	1202.8
	CV	16.6	20.5	25.2	20.8
	CT	84.5	86.3	77.8	82.9
Bega	Mean	101.4	92.6	119	104.3
	CV	57.6	84.8	68.8	70.4
	CT	7	6.7	7.8	7.2
Annual	Mean	1457.2	1384.3	1519.5	1453.7
	CV	16	21	25.4	20.8

For kiremt, the mean CV was 20.8%; CV revealed high (CV=25.2%) in Wereta and less (CV = 16.2%) variability in Wanzaye. The mean total rainfall amount for belg and bega were 146.5 and 104.3 millimeters; they varied from 96.9-218.3 mm and 92.6-119 mm, respectively. Bega rainfall was extremely variable (CV > 57%) for all stations. As compared to kiremt season, the Belg rainfall was more variable. This agrees with the study by (Birara *et al*., 2018; Getachew, 2017). Based on Hare (1983) classification, Fogera plain has been vulnerable to drought during Belg season (CV > 30%). The maximum and the minimum percentage for kiremt rainfall contribution to the mean annual total were observed in Addis Zemen (86.3%) and in Wereta (77.8%) this is similar result with (Birara *et al.*, 2018; kelemu, 2021) kiremt rainfall had much more contribution to the annual total rainfall of the South Gondar Zone.

The mean annual precipitation concentration index (PCI) value was 23 for Wanzaye station, which indicates very high concentrations of annual rainfall distribution, this result confirms with (Dawit *et al*., 2019*)*. The value of PCI in the year of 1996, 1997,2008,2014,2016 and 2019 were above 16 and below 20 so they indicate high concentrations of annual rainfall distribution. While remain years were lies above 20 indicate very high concentrations of annual rainfall distribution showed in Fig 4.1.

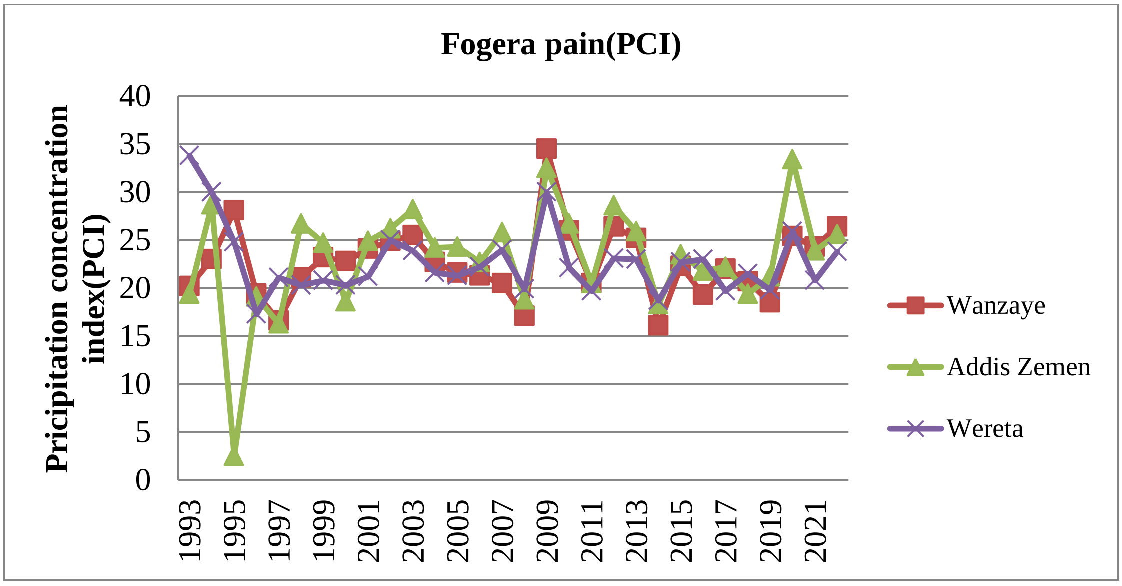

Figure 4.1. Precipitation concentration index (PCI %)

Mean annual precipitation concentration index (PCI) value was 23.6 for Fogera (Wereta station) which indicates very high concentrations of annual rainfall distribution precipitation concentration index (PCI), this result confirms with (Birara *et al.*, 2018; Dawit *et al*., 2019). The value of PCI in the year of 1996,2008,2011,2014,2017 and 2019 were above 16 and below 20 so they indicate high concentrations of annual rainfall distribution; while remain years were lies above 20 indicate very high concentrations of annual rainfall distribution. Mean annual precipitation concentration index (PCI) value was 23.1 for Addis Zemen station, which indicates very high concentrations of annual rainfall distribution precipitation concentration index (PCI). The value of PCI in the year of 1993, 1996, 1997, 2008, 2014 and 2018 were above 16 and below 20 so they indicate high concentrations of rainfall distribution; while remain years were lies above 20 indicate very high concentrations of annual rainfall distribution. Therefore in Fogera plain over all mean PCI were 23.1 which show very high concentrations of annual rainfall distribution. Decrease in annual rainfall may be due to fact that, some years recorded very less rainfall, which might have generally influenced overall trend. This means that even though annual rainfall decreased over period, rate of decrease was uneven. Less recordings of rainfall in some periods of years may be harmful to crop production especially rice which need excessive rainfall during reproductive (fruit development) stages.

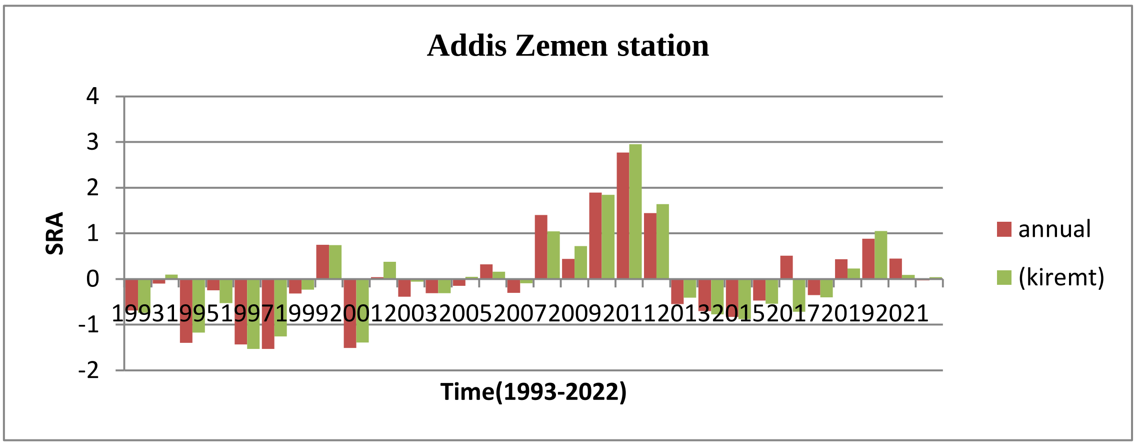

Figure 4.2. Standardize anomaly index (SAI) at Addis Zemen station (1993-2022)

Standardized rainfall anomaly index (SAI) calculated for a period of 30 years (1993-2022) indicated that the annual rainfall of Addis Zemen shows positive anomalies for 40% and extremely dry conditions with negative anomalies for 60% during recent years. *Kiremt* rainfall shows positive anomalies for 46.6% and extremely dry conditions with negative anomalies for 53.3%. The result of standardized anomalies of rainfall in the Figure shows that the area has experienced a significant number of drought years 2017, 2018,2019,2020,2021 and 2022. Extreme drought occurred in 1994. Heavy rainfall occurred in 1995, 1997, 2002 and 2009 in Addis Zemen.

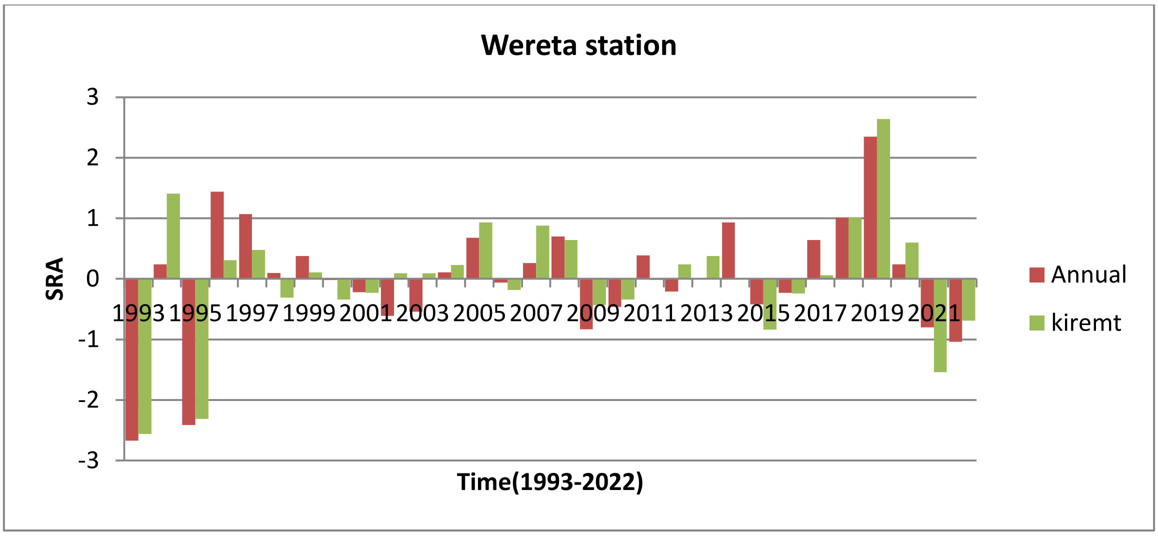

Figure 4.3. Standardize anomaly index (SAI) at Wereta station (1993-2022)

Standardized rainfall anomaly index (SAI) calculated for a period of 30 years (1993-2022) indicated that the annual rainfall of Wereta station shows positive anomalies for 50% and extremely dry conditions with negative anomalies for 50% during recent years. *Kiremt* rainfall shows positive anomalies for 53.3% and dry conditions with negative anomalies for 46.6%. Heavy rainfall occurred in 1997, 2005, 2006, 2008, 2014, 2018 and 2019. Extreme drought occurred in 1993, 1995 and 2009. Severe drought occurred in 2021 and 2022 in Wereta, this is consistent with the studies of (kelemu, 2021).

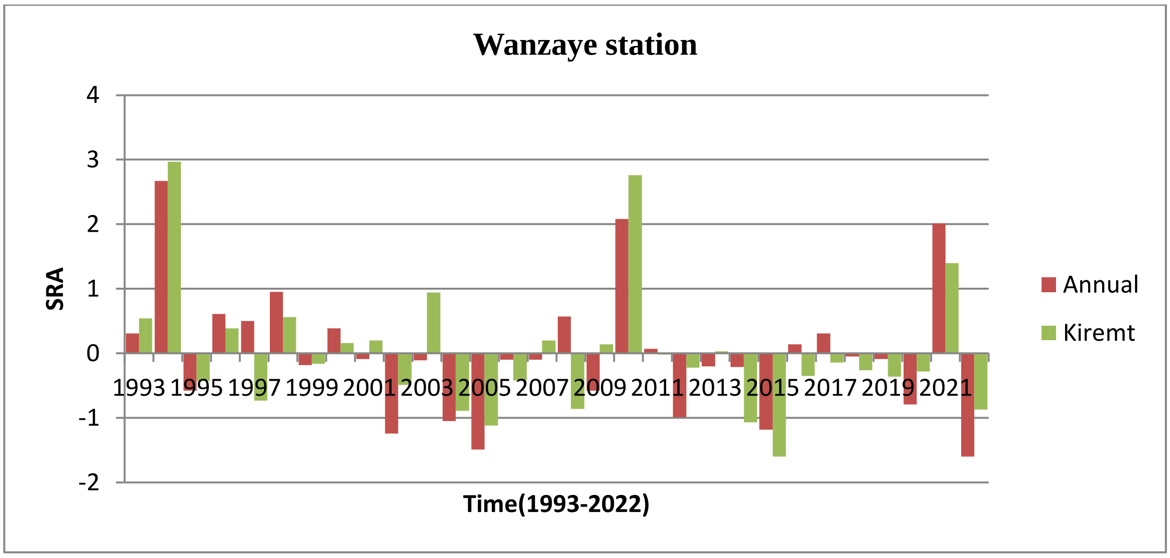

Figure 4.4. Standardize anomaly index (SAI) at Wanzaye station (1993-2022).

Standardized rainfall anomaly index (SAI) calculated for a period of 30 years (1993-2022) indicated that the annual and *kiremt* rainfall of Wanzaye station shows positive anomalies for 40% and dry conditions with negative anomalies for 60%. Statistical description of seasonal rainfall characteristics such as onset date, cessation date and length of growing period is depicted in Table 4.5. The result revealed that onset of kiremt rainy season ranges between 150 and 176 days of the year. The earliest onset of kiremt season occurs on the first of June 150 days of the year in Dera and the delayed start of the kiremt season was 176 in Libo kemkem district. The variability in onset date was generally very low and remains below 10 % at all sites. CV was 3 %, 3 % and 4 % for Wanzaye, Wereta and Addis Zemen area respectively. The standard deviation for mean start of the season showed high deviations about 4.5, 5.6 and 6 days at Wanzaye, Wereta and Addis Zemen respectively. The length of kiremt season CV was 5 %, 6 % and 8 % for Wanzaye, Wereta and Addis Zemen area respectively. From this point of view, the start and length of kiremt season was less predictable at Addis Zemen as compared to Wanzaye and Wereta. The findings of the rainfall variability analysis from this study are similar to those reported for Wereta stations by (Molla et al., 2020).

Table 4.5. Onset date, cessation date and length of growing period

	Wanzaye station			Wereta station			Addis Zemen station		
Summary	Onset	End date	LGP	Onset	End date	LGP	Onset	End date	LGP
Maximum	168	312	158	169	303	150	176	298	138
Minimum	150	285	123	152	282	116	152	268	101
Mean	156	299	142	160	292	132	163	285	121
SD	4.5	5.7	7.7	5.6	5.5	8.6	6	7.3	9.5
CV (%)	3	2	5	3	2	6	4	3	8

4.1.4 Annual, Seasonal and monthly temperature variability

Results of temperature analysis indicated that, mean monthly minimum temperature ranges between 8.3 °C to 12.8 °C while mean monthly maximum temperature varies between 25.3 °C and 32.1 °C (Table 4.6). The study further indicated that months such as October, November, December, January and February have recorded lower minimum temperature. Based on the result, May was the hottest whilst December was coldest for the past three decades in Addis Zemen. The result also suggests that monthly minimum temperature in December and November were highly variable with CV of 34.1 % and 30 % respectively. Mean *kiremt* maximum temperature CV was 4 % and minimum temperature CV was 17.2%. Mean annual maximum temperature CV was 4.1 % and minimum temperature CV was 15.9 %. Mean monthly, *kiremt* and annual maximum temperature characterized by less variability compared to monthly, *kiremt* and annual minimum temperature. As shown in Table 4.6, CV was less than 10 % in all monthly, *kiremt* and annual indicating that maximum temperature was more stable in the study area throughout the year in the past three decades.

Table 4.6. Annual, seasonal and monthly temperature variability

	Addis Zemen				Wereta				Wanzaye			
	Tmax(°c)		Tmin(°c)		Tmax(°c)		Tmin(°c)		Tmax(°c)		Tmin(°c)	
	mean	CV	Mean	CV	mean	CV	Mean	CV	mean	CV	Mean	CV
Jan.	30.4	5.6	8.7	28.5	28.4	4	11.6	36.1	27.7	7.4	10.2	15.4
Feb.	31.8	5.4	10.6	20.9	29.6	5.2	13.3	26.7	29.8	5.5	11.9	9.7
Mar	31.1	8.5	11.6	19.7	30.2	5.3	14.2	24.1	30.7	5.8	13.6	8.8
Apr	31.4	9.5	12.2	19.3	30.2	5.4	14.6	22.7	30.8	6.3	14.7	8.7
May	31.5	5.5	12.8	15.9	29.7	6.2	15.1	25.1	30.6	7.2	15.2	13.6
Jun	27.9	7	12.7	16.5	27.3	4.1	14.3	17.8	27.2	6.4	14.2	8.4
Jul	25.3	5.2	12.3	19.5	25	7	14.1	20.3	24	7.8	14.3	6.2
Aug	25.3	5.8	12.6	20.1	24.7	4.1	14.4	19.2	23.9	6.2	14.2	7.2
Sep	27.3	6.1	12.3	19.4	26	7.9	14.1	18.3	25.3	4.6	13.7	8.2
Oct	29.2	6.5	10.6	23.2	26.8	5.5	13.5	18.8	26.9	8.5	13.2	11.6
Nov	29.6	5.1	8.9	30	27.6	5.2	12.2	26.8	27.3	6.9	11.5	17.7
Dec	29.7	8.2	8.8	34.1	27.8	6.3	11.8	30.1	27.4	7.6	10.3	17.8
Ann	29.3	4.1	11.1	15.9	27.8	3.3	13.6	19.9	27.6	5.6	13.1	7.5
k/mt	26.5	4	12.5	17.2	25.7	3.5	14.2	17.7	25.1	5.7	14.1	6.6
Belg	31.7	6.4	12.2	15.6	30	4.8	14.5	23.1	30.4	5.9	14.5	8.8

The study further indicated that months such as October, November, December, January and February have recorded lower minimum temperature. May was the hottest whilst January was coldest for the past three decades in Wereta station. The result also suggests that monthly minimum temperature in January and December were highly variable with CV of 36.1% and 30.1% respectively. Mean kiremt maximum temperature CV was 3.5% and minimum temperature CV was 17.7. Mean annual maximum temperature CV was 3.3% and minimum temperature CV was 19.9 in Wereta station. Mean monthly, *kiremt* and annual maximum temperature characterized by less variability compared to monthly, *kiremt* and annual minimum temperature.

Mean monthly minimum temperature ranges between 10.3 °C to 15.15 °C while mean monthly maximum temperature varies between 23.9 °C and 30.8 °C in Wanzaye station (Table 4.6). The study further indicated that months such as November, December, January and February have recorded lower minimum temperature. Based on the result, May was the hottest whilst December was coldest for the past three decades in Wanzaye. The result also suggests that monthly minimum temperature in November and December were highly variable with CV of 17.77 % and 17.78 % respectively. On the other hand, monthly minimum temperature in the month of June, July, August and September was less variable with CV 8.4 %, 6.16 %, 7.17% and 8.22 % respectively. Mean *kiremt* maximum temperature CV was 5.7 % and minimum temperature CV was 6.67. Mean annual maximum temperature CV was 5.6 % and minimum temperature CV was 7.5. Mean monthly, *kiremt* and annual maximum temperature characterized by less variability compared to monthly, *kiremt* and annual minimum temperature. Generally minimum temperature shows higher variability as compared with maximum temperature in all station, all monthly, *kiremt* and annual maximum temperature was more stable in the study area throughout the year in the past three decades.

4.2. Projected future climate (rainfall and temperature) changes in Fogera plain

4.2.1 Model performance

Rainfall climate data was downscaled from BCC-ESM2 and temperature climate data was downscaled from MRI-ESM2. Bias correction method selected from CMhyd software was based on their performance. CMhyd software has five methods (linear scaling, delta change, power transformation distribution mapping and local intensity scaling) for rainfall and four methods (linear scaling, variance scaling, delta change and distribution mapping) used for temperature projection. The observed and simulated data were compared to check the suitability of the method, whether it is fitting or no appendix (Table 6.2). Efficiency criteria were calculated by correlation. Based on the result high correlation of observed and simulated bias correction method was selected. Delta change shows high correlation for both rainfall and temperatures than other CMhyd bias correction methods. Because delta change method shows excellent agreement between observed and simulated rainfall appendix (figure 6.1-6.6).

4.2.2 Projected Rainfall Change

Projected change of annual, *kiremt* and *belg* rainfall totals in the study area is presented in Table 4.7. The result showed that decreasing trend of annual, *kiremt and belg* rainfall totals in all scenarios (2025-55) and (2056-2086) time periods in Addis Zemen station. *Kiremt* rainfall will decrease by 36.4%, 28.9% and 23.8% in the 2025-55 and by 31.9%, 41% and 22.3% in 2056-86 with SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios respectively. This shows the future climate would be an occurrence of shortage of rain fall which affects agricultural activities and crop growth and productivity. Annual rainfall total is expected to decrease by 21.3%, 10.4 % and 7.9% in 2025-5 SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios respectively and 2056-86 decrease by 18.4%, 13.8 % and increased by 3.3 % SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios respectively. As compared to the base period, annual and kiremt rainfall is expected to increase in Wereta stations by all scenarios in both time periods as shown in Table 4.7. These are an implication of future kiremt season in the area would be occurred flooding and affect agricultural activities. Annual rainfall would be increased by 3.6 % to 14.2 % and 10.3 % with SSP 1-2.6, SSP 2-4.5 and SSP5-8.5 scenarios in 2025-55 respectively. In Wereta stations 7.9 %, 10.8 % and 12.04 % amount of annual rainfall expected to increase by 2056-2086 with SSP 1-2.6, SSP 2-4.5 and SSP5-8.5 scenarios respectively. Annual rainfall at Wanzaye stations is expected to increase by 2.7 % and 10.4 % with SSP12.6 and SSP5-8.5 by 2025-55 respectively. Likewise, by 2056-86 it is expected to increase by 4.1%, 7.1% and 14.4 % with SSP1-2.6, SSP2-4.5 and SSP5-8.5 respectively. *Kiremt* rainfall is expected to increase by 6.6% and 12.9% in 2025-55 SSP1-2.6 and SSP5-8.5 scenarios respectively and 7.2%, 10.4% and 17.9% in 2056-86 with SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios respectively. Similar to the present study, different researchers in the country also revealed spatial variability of future rainfall in Ethiopia. For example, (Almazroui *et al.*, 2020; Getachew & Manjunatha, 2021; Alaminie *et al*., 2021; Worku *et al.*, 2022). These are an implication of climate change; in the future kiremt season there would be flooding that effect on rice crop because excess rainfall causes submergence of rice at seedling and vegetative stage not only these but also it causes an effect on the ripening stage.

Table 4.7. Addis Zemen, Wereta and Wanzaye station projected change of kiremt, Belg and annual rainfall in (mm)

Station	SSP	2025-2055			2056-2086		
		Annual	*kiremt*	*Belg*	Annual	*kiremt*	*Belg*
Addis Zemen	baseline	1314.5	1138.5	118.6	1314.5	1138.5	118.6
	SSP1-2.6	1022.8	723.7	37.6	1072.7	774.9	54
	Δ	-291.6	-414.8	-81	-241.8	-363.6	-64.5
	Δ%	-22.2	-36.4	-68.3	-18.4	-31.9	-54.4
	SSP2-4.5	1185.2	808.6	51.3	1155.3	807.6	49.6
	Δ	-129.3	-329.9	-67.3	-159.2	-330.9	-69
	Δ%	-9.8	-28.1	-56.7	-12.1	-29.1	-58.2
	SSP5-8.5	1210	867.4	38	1359.5	930.6	47.5
	Δ	-104.5	-271.1	-80.6	45	-207.9	-71.1
	Δ%	-7.9	-23.8	-68	3.4	-18.3	-60
Wereta	baseline	1507	1309.3	122.1	1507	1309.3	122.1
	SSP1-2.6	1560.7	1419	96.8	1625.4	1441.8	132.9
	Δ	53.7	109.7	-25.3	118.4	132.5	10.8
	Δ%	3.6	8.4	-20.7	7.9	10.1	8.9
	SSP2-4.5	1721.6	1322.8	141	1669.6	1344.9	133.6
	Δ	214.6	13.5	18.9	162.5	35.6	11.5
	Δ%	14.2	1	15.5	10.8	2.7	9.4
	SSP5-8.5	1662	1546.1	119.6	1694.1	1646.1	111.4
	Δ	155	236.8	-2.5	187.1	336.8	-10.7
	Δ%	10.3	18.1	-2	12.4	25.7	-8.8
Wanzaye	baseline	1481.8	1258.2	119.4	1481.8	1258.2	119.4
	SSP1-2.6	1522.2	1341.3	133.9	1543.1	1349.3	148.8
	Δ	40.4	83.1	14.5	61.3	91.2	29.4
	Δ%	2.7	6,6	12.2	4.1	7.2	24.6
	SSP2-4.5	1609.7	1390.2	152.5	1594.4	1403.6	142.1
	Δ	-51.3	-54.2	6.7	112.6	145.4	22.7
	Δ%	-3.2	-3.9	4.7	7.1	10.4	16
	SSP5-8.5	1636.2	1420.5	160.8	1695.8	1484	147.9
	Δ	154.4	162.4	41.4	214	225.8	28.5
	Δ%	10.4	12.9	34.7	14.4	17.9	23.8

Δ = Change, Δ%=Change in percent

4.2.3 Projected Temperature change *(*Maximum and Minimum temperature)

Table 4.8 shows the predicted changes of temperature at different stations in Fogera plain. The result revealed that the stations will get warmer than today, but the magnitude of change may depend on location of the station and scenarios considered. For Addis Zemen station, the downscaled temperature showed an increasing trend in all future time horizons for all SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios. The average annual maximum temperature in 2025-55 would be increased by 1.5 °C, 1.2 °C and 1.7 °C SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario respectively. For the 2056-86 periods the average annual maximum temperature would be increased by 1.4 °C, 2.1 °C and 3.3 °C for SSP1-2.6, SSP2-4.5 and SSP5-8.5 respectively. This prediction was consistent with many previous studies (Getachew & Manjunatha, 2021; Worku et al., 2022). Minimum and maximum Temperature showed an increasing trend but rainfall is decreasing at Ribb catchment, Lake Tana basin (Worku *et al*., 2022).

For Wereta station, the downscaled maximum temperature showed an increasing trend in all future time horizons for all SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios. The average annual maximum temperature in 2025-55 would be increased by 1.4 °C, 1.4 °C and 1.6 °C for SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario respectively. For the 2056-86 periods the average annual maximum temperature would be increased by 1.4 °C, 2.8 °C and 3.5 °C for SSP1-2.6, SSP2-4.5 and SSP5-8.5 respectively (Getachew, 2018; Getachew & Manjunatha, 2021). For Wanzaye station, the downscaled maximum temperature showed an increasing trend in all future time horizons for all SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios. The average annual maximum temperature in 2025-55 would be increased by 2.6 °C, 0.9 °C and 1.7 °C SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario respectively. For the 2056-86 periods the average annual maximum temperature would be increased by 1.8 °C, 1.8 °C and 3.1 °C for SSP1-2.6, SSP2-4.5 and SSP5-8.5 respectively (Getachew & Manjunatha, 2021; Worku *et al*., 2022).

For Addis Zemen station, the downscaled minimum temperature showed an increasing trend in all future time horizons for all SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios Table 4.8. The average annual minimum temperature in 2025-55 would be increased by 1.8 °C 1.5 °C and 2.1 °C SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario respectively. For 2056-86 periods the average annual minimum temperature would be increased by 1.7 °C, 2.3 °C and 3.5 °C for SSP1-2.6, SSP2-4.5 and SSP5-8.5 respectively. For Wereta station, the downscaled minimum temperature showed an increasing trend in all future time horizons for all SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios Table 4.8. The average annual minimum temperature in 2025-55 would be increased by 0.9 °C, 0.4 °C and 1.2 °C for SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario respectively in Wereta station.

Table 4.8. Future temperature change in three stations

Season	Maximum temp.						Minimum temp					
	SSP1-2.6		SSP2-4.5		SSP5-8.5		SSP1-2.6		SSP2-4.5		SSP5- 8.5	
	near	far	near	far	near	far	near	far	near	far	near	far
Addis Zemen Station												
Annual	1.5	1.4	1.2	2.1	1.7	3.3	1.8	1.7	1.5	2.3	2.1	3.5
Kiremt	1.4	1.4	0.9	2	1.4	3.2	1.8	1.9	1.4	2.3	2.3	3.5
Belg	1.9	1.5	1.7	2.2	2.2	3.5	1	0.9	0.9	1.7	1.6	2.9
Wereta station												
Annual	1.4	1.4	1.4	2.8	1.6	3.5	0.9	0.7	0.4	1.7	1.2	2.5
Kiremt	1	1	1.1	3.1	1.4	3.5	0.8	0.8	0.4	1.7	1.2	2.5
Belg	1.3	1.3	1.6	3.0	1.7	3.4	0.7	0.5	0.2	1.5	1.1	2.3
Wanzaye station												
Annual	2.6	1.8	0.9	1.8	1.7	3.1	0.4	2.1	3.1	3.9	3.0	5.1
Kiremt	2.3	1.8	0.9	2.1	1.7	3.3	-0.3	1.1	1.2	2.1	1.0	3.4
Belg	2.5	1.6	0.8	1.7	1.7	2.9	-0.5	1.8	2.9	3.8	2.9	4.9

near =2025-2055 , far =2056-2086

For the 2056-86 periods the average annual minimum temperature would be increased by 0.7 °C, 1.7 °C and 2.5 °C for SSP1-2.6, SSP2-4.5 and SSP5-8.5 respectively. This prediction was consistent with many previous studies (Getachew & Manjunatha, 2021; Worku *et al.*, 2022). For Wanzaye station, the downscaled minimum temperature showed an increasing trend in all future time horizons for all SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios Table 4.8. The average annual minimum temperature in 2025-55 would be increased by 0.4 °C, 3.1 °C and 3 °C SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenario respectively. For the 2056-86 periods the average annual minimum temperature would be increased by 2.1 °C, 3.9 °C and 5.1 °C for SSP1-2.6, SSP2-4.5 and SSP5-8.5 respectively. This prediction was consistent with many previous studies (Adem *et al*., 2016; Getachew & Manjunatha, 2021; Worku *et al*., 2022).

4.3 Projected climate impact on rice future productivity in Fogera plain.

4.3.1 Model performance

Performance of Correlation and multiple linear regression rice predicting models was validated. Correlation between observed and simulated rice productivity (2015-2022) in Wanzaye was 0.9 and Wereta station 0.9 and correlation between observed and simulated rice productivity (2019-2022) in Addis Zemen station was 0.8.

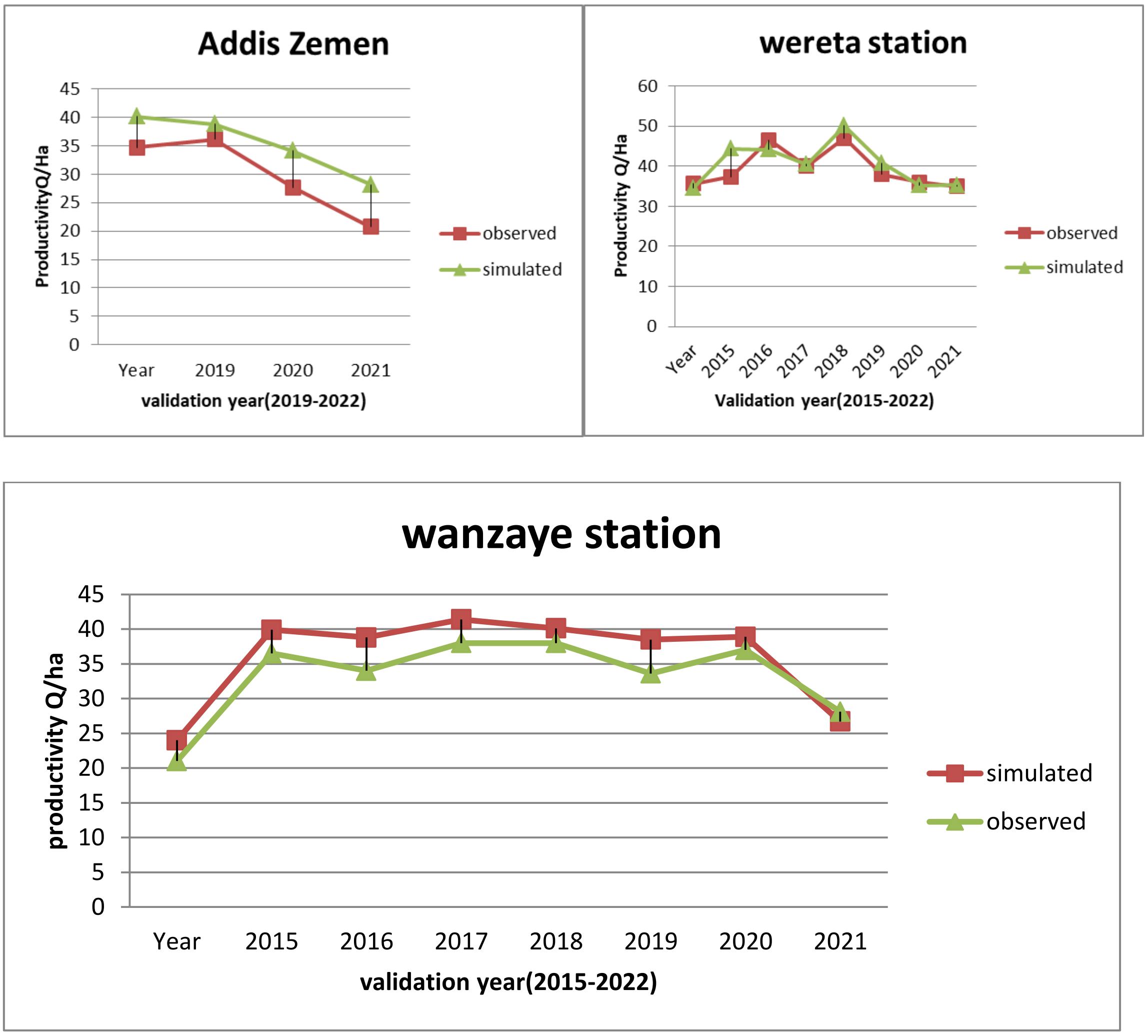

Figure 4.5. Observed and simulated Correlation of rice productivity 2015 - 2022 in (Wanzaye and Wereta) and 2019-2022 Addis Zemen station.

4.3.1 Relation between Observed Climate Variability and Rice Productivity

The correlation coefficients are computed between rice yields with different rainfall features at Wanzaye, Wereta and Addis Zemen stations were shown in (Table 4.9). Rice yields showed the negative correlation for the maximum temperature for both September and *kiremt* season in all stations. The correlation between the maximum temperature and observed rice yield and was found to be -0.57,-0.54 and -0.76 in September and -0.57,-0.62 and -0.77 in *kiremt* season at Wanzaye, Wereta and Addis Zemen stations respectively. That means increase in maximum temperature has large negative impacts on net rice yield. The result implied that increasing temperature load leads to higher rates of evapotranspiration and heat stress that in turn might limit crop yield potential (IPCC, 2014). Similarly correlations between the observed rice yield and minimum temperature also showed negative correlation and was found to be- 0.16,-0.07 and -0.18 in September and -0.3,-0.08 and -0.13 *kiremt* season at Wanzaye, Wereta and Addis Zemen stations respectively. This result is contradicted with Getachew, (2017) predicts that an increase in minimum and maximum temperature will cause an increase in yield of rice but Similar results and facts were shown by (Adhikari *et al*., 2017).

Table 4.9. The relationship between climate and the rice yield in three stations

Area	Wanzaye	Wereta	Addis Zemen
kiremt Rf	0.59	0.70	0.71
Onset	-0.81	-0.67	-0.77
Cessation	0.32	0.27	0.45
Lgp	0.72	0.60	0.83
September Tmax	-0.57	-0.54	-0.76
kiremt Tmax	-0.57	-0.62	-0.77
September Tmin	-0.16	-0.07	-0.18
kiremt Tmin	-0.03	-0.08	-0.13

Rice yields showed the strong positive correlation for *kiremt* total rainfall. Correlation between *kiremt* rainfall and observed rice yield was found to be 0.59, 0.70 and 0.71 in Wanzaye, Wereta and Addis Zemen station respectively. That means increase *kiremt* season rainfall had positive impacts and less rainfall could be harmful to rice crops and affect its yield. This result in line with the finding of (Poudel, & Shaw, 2016; Getachew, 2017; Adhikari *et al.*, 2017; Molla *et al.*, 2020). Furthermore, the present results are congruent with (IPCC, 2012) that increase in rainfall causes increases in crop yield, a reduction in rainfall causes a decline in net yield of crops especially crops that need considerable amount of water to survive. As observed from the results obtained on the relationship between the climatic factors and rice yield. Rice yield has positive and weak correlation with end of the season but positive and strong correlation with onset and length of growing season. Correlation between end of the season and onset of rainy season with observed rice yield was 0.32, 0.27 and 0.45 and -0.81,-0.67 and -0.77 in Wanzaye, Wereta and Addis Zemen station respectively. Correlation between length of growing season and rice yield was 0.72, 0.60 and 0.83 in Wanzaye, Wereta and Addis Zemen station respectively. Onset and length of growing season are the most essential determinate factors in the production of rice in Fogera plain. The findings of the rainfall characteristics correlation with rice yield analysis from this study are similar with (Molla *et al.*, 2020). Early onset of rainy season is important for agricultural operations such as land preparation. Delay in the start of rainy season delays the time of sowing/planting under rain fed conditions (Manikandan et al., 2017) and delayed start of cropping season results to water stress in flowering and ripening periods, lead to crop failure (Nunn *et al.*, 2017). Even a week delay in the onset of rain is found to have significant impact on crop yield. Seed drop, mature crop germination and harvested crop decay were the result of unseasonal rainfall.

4.3.2 Results on Multiple Regression Analysis

The combined effects of both rainfall and temperature on rice yields were computed using the multiple linear regression models. The values of the regression coefficients indicate the variations in the rice yields ranging from 77 % (0.77) in the case of Wanzaye area and 62 % (0.62) in the case of Wereta and in case of Addis Zemen area the variation ranging from 64 % (0.64). Whereas 23 %, 38 % and 36 % of the variation in rice yield in Wanzaye, Wereta and Addis Zemen respectively was explained by other influential factor .These coefficients can be used to assess the real effects of climate variables in the changes in the rice yields per hectare considered in this study. In addition, the sign of the coefficients indicates the direction of change in the rice yield versus climate variable changes. Regression equation was derived for Addis Zemen, Wereta and Wanzaye station.

- ❖ Addis Zemen station

- ✓ Yield=52-2.4 *kiremt* Tmax(°C)-0.13 SepTmax (°C)+0.001 *Kiremt* Rf (mm) +0.51 Lgp (day) -0.7 onset (day)+5.1

❖ Wereta station

✓ Yield=88-0.28 *kiremt T*max (°C) -.72 SepTmax (°C) +0.02 *Kiremt* Rf (mm) +0.045 Lgp (day) -0.35 onset (day) +3.2

❖ Wanzaye station

✓ Yield=142-3.1 *kiremt T*max (°C) -1.5 SepTmax (°C) +0.001 *Kiremt* Rf (mm) +0.2 Lgp (day) -0.55 onset (day)+4.1

4.3.3 Impact of future climate on rice productivity

The simulated yield of rice is varied with location and type of scenarios used. However, on average, rice yield is expected to decrease by 2.9-11.4% in SSP 2-4.5 and 37-43 in SSP 5-8.5 scenarios in Addis Zemen station as shown below Table.

Table 4.10. Projected yield change from base line under three scenarios in three Stations

Station	Wanzaye			Wereta			Addis Zemen		
Baseline yield	31.0 quintal /hectare			36 quintal / hectare			35 quintal / hectare		
Scenario	SSP1-2.6	SSP2-4.5	SSP5-8.5	SSP1-2.6	SSP2-4.5	SSP5-8.5	SSP1-2.6	SSP2-4.5	SSP5-8.5
2025-55	38.3	35	30	42	36	32	38	34	22
2056-86	40	32	24	43	36	30	41	31	20
Change(Δ)									
2025-55	7	4	-1	6	0	-4	3	-1	-13
2056-86	9	1	-7	7	0	-6	6	-4	-15
Δ%(change in percent)									
2025-55	22.6	12.9	-3.2	16.7	0	-11.1	8.6	-2.9	-37
2056-86	29	3.2	-22.6	19.4	0	-16.7	17.1	-11.4	-42.8

With period of analysis and the study location rice yield show different amount under different future scenarios, with increase under SSP1-2.6 and decrease under SSP5-8.5 in Fogera plain. Based on growing location, rice production is more affected due to future climatic conditions at Addis Zemen relative to Wereta and Wanzaye station. Yield of rice under the projected future climate would be varied also with scenarios (SSP's) assumed to project the future climate change scenario. Yield of rice will be expected to increase under the SSP1-2.6 scenario in all growing locations but decrease under the SSP5-8.5 scenario in all growing locations. The findings of this study are similar with (Fricko *et al.,* 2016) who reported that there will be high land productivity (high crop yield) in SSP1-2.6 in the future time period.

CHAPTER 5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study was conducted the impacts of climate change and variability on past and future rice productivity in Fogera plain, Lake Tana sub basin Ethiopia. Annual and seasonal rainfall show positive trend in Wereta and Addis Zemen but shows negative trend in Wanzaye station. Increasing trends in start date of season and decreasing length of growing season *kiremt* growing season were observed. *Kiremt* rainfall had much more contribution to the annual total rainfall. Annual rainfall distribution was very high concentrations and high seasonal rainfall variability in the past three decades in Fogera plain.

Projected annual rainfall totals would have increase in Wereta and Wanzaye. This increase rainfall in the sub-basin results in a higher risk of flood events in the future but decreasing in Addis Zemen in all scenarios except SSP5-8.5 (2056-2086). Both low and excessive rainfalls can have a negative impact on rice yield. Future minimum and maximum temperature rise in all SSP scenarios, this is difficult for rice production and productivity. Because rice are temperature sensitive; where an increase in temperature affects the reproductive and developmental stages. Rice yield has positive and strong correlation with *kiremt* rainfall and length of growing season. Onset and length of growing season are the most essential determinate factors in the production of rice in Fogera plain. Yield of rice will be expected to increase with climate policies in all growing locations but decrease under the absence of climate policies in all growing locations Fogera plain.

Generally, the increase in projected temperature and variable rainfall contribute for the predicted yield reduction in the study areas. Moreover, increase in temperature would increase the evapotranspiration demand of the atmosphere and hence creates moisture deficit in the root zone, which in turn leads to yield reduction. This will have a far reaching effect on the livelihood of the community who depend on rice production for food and feed.

5.2 Recommendation

From the result of the study, the following recommendations are suggested.

- Mitigation (emission reduction) measures should be taken by using standard fuel-saving stoves, reduce number of cattle and use organic fertilizer application.
- Adaptation measures should be taken at community (autonomous) level.
  - ✓ In the short run, apply appropriate planting dates, short maturing and better tolerance to adverse climate impacts.
  - ✓ In the long run the dry months of June and September need additional water in the future they should be use local irrigation.
- Adaptation measures should be taken at institutional levels.
  - ✓ In the short run, metrological agency and agricultural sectors should help farmers by developing climate forecasting for rice farming by giving early warning systems and improve farmer's knowledge about proper use of weather information.
  - ✓ In the long run government should be construct large reservoir for water storage.

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APPENDIX

Rainfall climate data is downscaled from BCC-ESM2 and temperature climate data is downscaled from MRI-ESM2 by delta change method.

Table 6.1 Correlation simulated climate variables by CMhyd method (linear scaling Delta change, power transformation, Distribution mapping, local intensity scaling, variance scaling) with observed (station data)

CMhyd method	Addis Zemen			Wereta			Wanzaye		
	Rainfall	Tmax	Tmin	Rainfall	Tmax	Tmin	Rainfall	Tmax	T Min
LS	0.6	0.89	0.71	0.68	0.76	0.76	0.7	0.82	0.82
DC	0.67	0.99	0.99	0.97	0.97	0.97	0.96	0.97	0.97
PT	0.5			0.6			0.52		
DM	0.54	0.7	0.7	0.6	0.72	0.72	0.6	0.8	0.8
LIS	0.58			0.5			0.6		
VS.		0.6	0.6		0.45	0.45		0.5	0.5

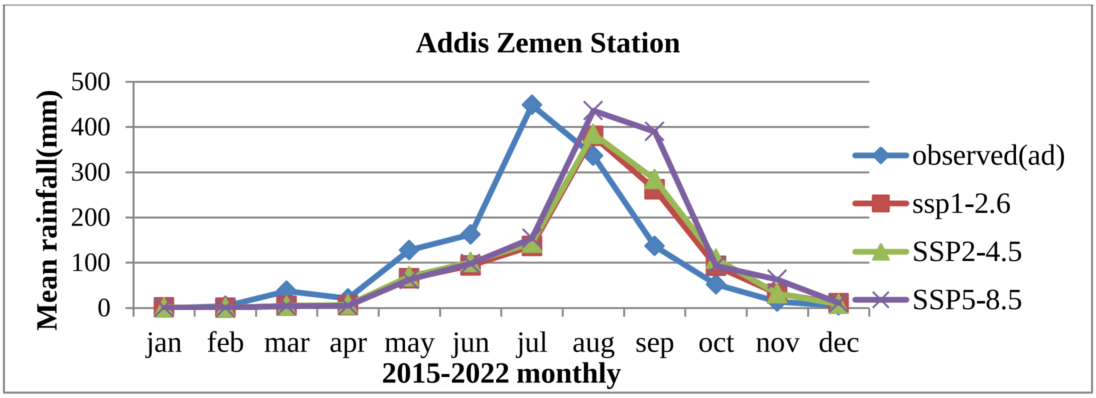

Figure 6.1. Correlation between observed and the simulated rainfall in Addis Zemen

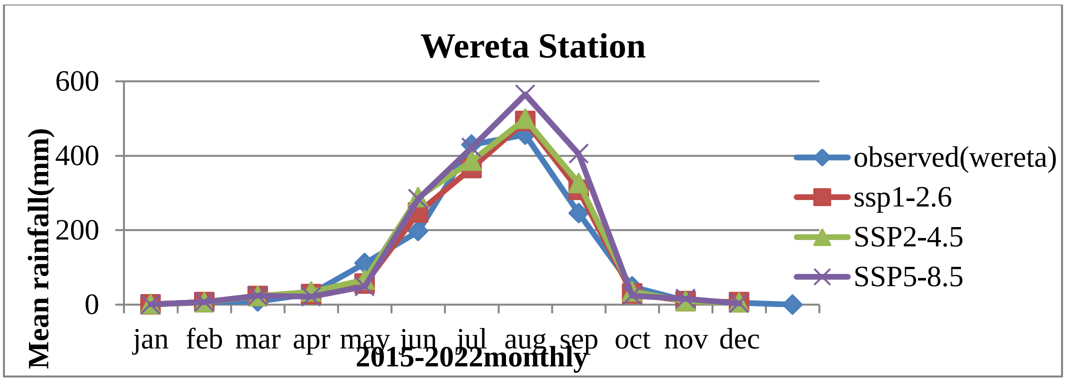

Figure 6. 2. Correlation between observed and the simulated rainfall in Wereta station

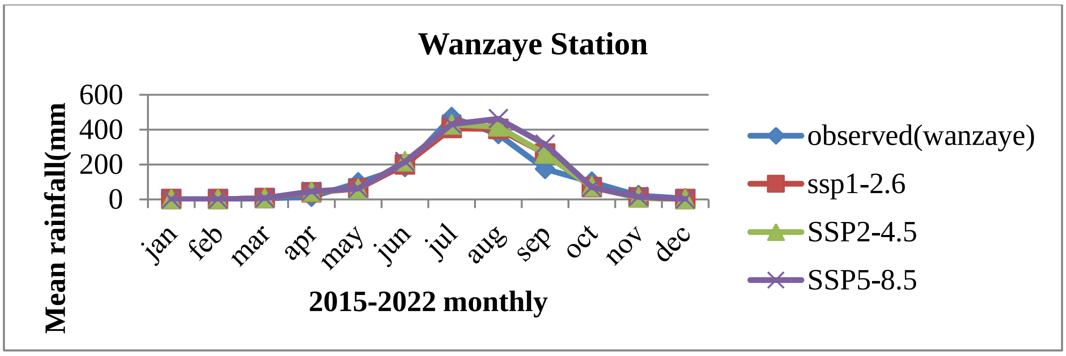

Figure 6. 3. Correlation between observed and the simulated rainfall inWanzaye station

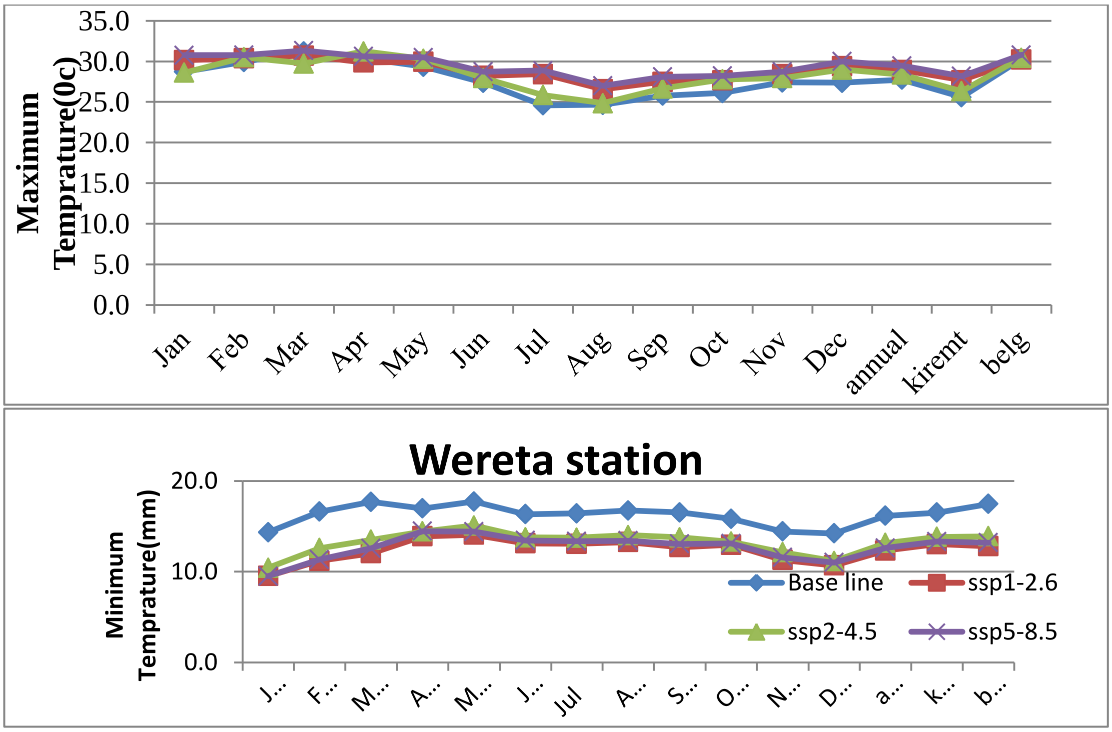

Figure 6.4. Correlation between observed and the simulated maximum and minimum temperature with Wereta station (2015-2022)

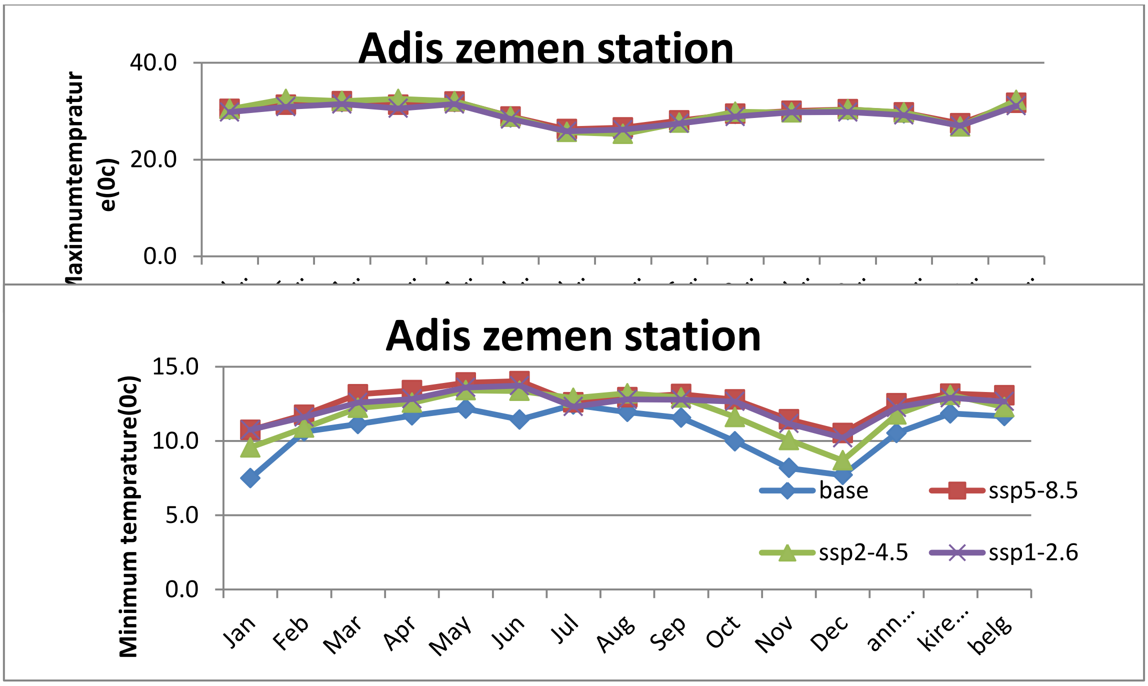

Figure 6.5. Correlation between observed and the simulated maximum and minimum temperature with Addis Zemen station (2015-2022)

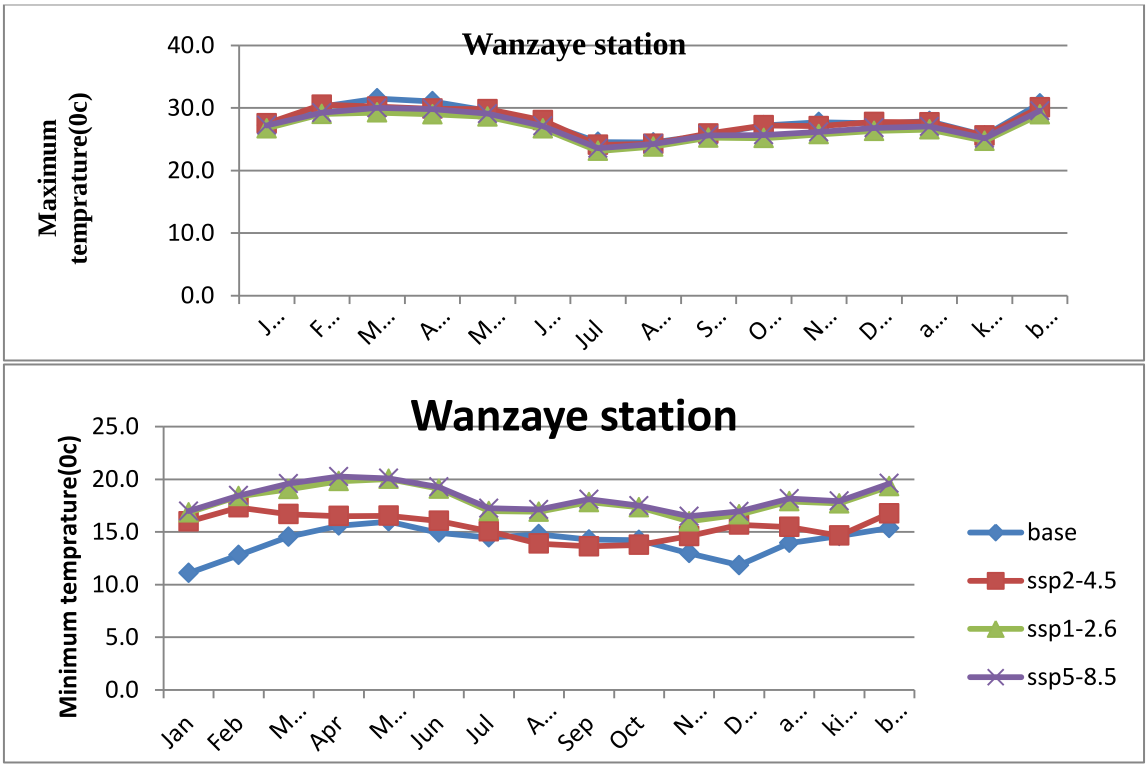

Figure 6.6. Correlation between the observed and the simulated maximum and minimum temperature with Wanzaye station (2015-2022)

BIOGRAPHICAL SKETCH

The author was born in the Amhara region, South Gondar Zone, Dera District on July 19, and 1982 E.C. He started his academic education at 19 89 at Korata primary school. He attended Korata primary school from 1989 to 1992 E.C. After completion of primary school, he attended elementary school from 1993 to 1996 E.C at Hamusit full-cycle school. After completion of elementary school 1997-1998 E.C, he attends high school classes at Anbesamie Secondary School; he attends preparatory classes at Wereta Preparatory School from 1999-2000 E.C. After passing the Higher Education Entrance Certificate Examination (HEECE), he joined Debre Markos University 2001 E.C and during his stay for three years at Debre Markos University, he studied Natural Resource Management (NaRM) and graduated with B.Sc. degree in June 2003 E.C. After that, in October 2021; he successfully passed the scholarship at Bahir Dar University and joined the school of graduate Program at Bahir Dar University, College of Agriculture and Environmental Sciences, to pursue his M.Sc. degree in Environment and Climate change.